1986 FIELD INVESTIGATION HYDROLOGY REPORT

FRENCH LIMITED SITE CROSBY, TEXAS

[redacted]

PREPARED FOR

ARCO CHEMICALS COMPANY

and

THE FRENCH LIMITED TASK GROUP

DECEMBER 19, 1986

PREPARED BY

Applied Hydrology Associates, Inc.

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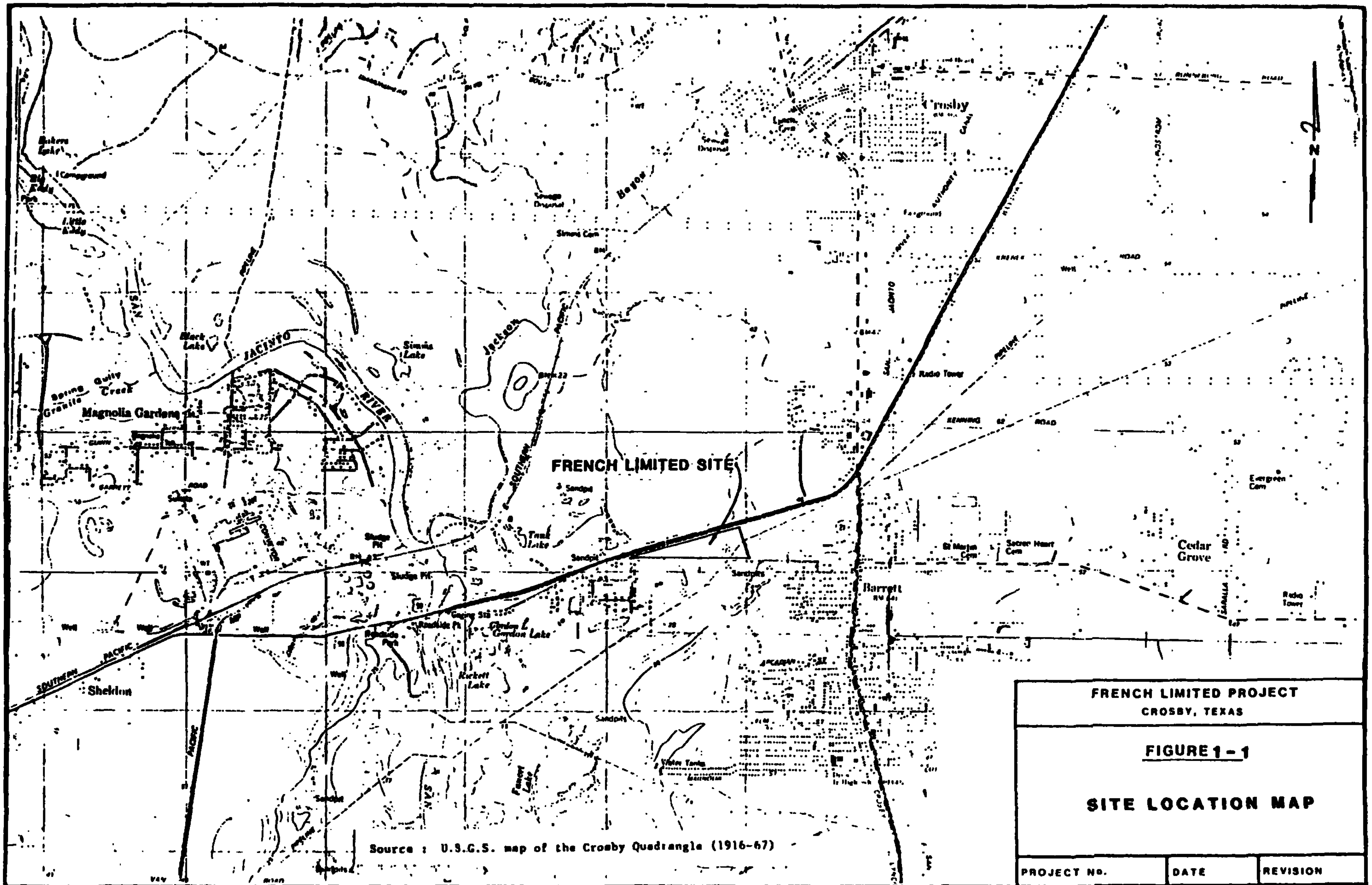
1.0 INTRODUCTION

The French Limited Site, an abandoned waste pit on 15 acres south of State Highway 90 near Crosby, Texas (Figure 1-1), has been designated for Remedial Investigation/Feasibility Study (RI/FS) under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). In December, 1982, the Texas Dept. of Water Resources, under a cooperative agreement with EPA, contracted to initiate a Remedial Investigation (RI). The field investigations were conducted and an initial RI report was completed by Lockwood, Andrews and Newman (LAN) in January, 1984. The French Limited Task Group was formed in late 1983 by potentially responsible parties to determine the most reasonable and environmentally acceptable remedial actions to be taken at the site. The Task Group contracted with Resource Engineering, Inc. (REI) to provide technical consulting services in support of the French Limited remedial investigations. A draft report documenting the additional site investigations developed by REI was issued by the Task Group in May, 1984. In April, 1985 upon EPA approval of a work plan, the French Limited Task Group entered into an Administrative Order to complete the RI investigations. A Draft RI report was submitted in February 1986 with additional responses submitted in April 1986.

The 1986 Field program for the French limited site was developed to address concerns raised by EPA following review of the Draft RI Report. One of the major concerns was the quantification of the degree of hydrologic communication between a shallow alluvial aquifer which has been contaminated by wastes deposited in the French Limited Lagoon and a lower aquifer zone located approximately 120 feet below grade at the site. The geologic and hydrologic data collected at the site strongly support the existence of a continuous clayey zone between the upper alluvial aquifer and lower aquifer zone that probably has the characteristics to effectively isolate the two zones. However, the existence of contamination in the lower zone suggests that communication with the overlying alluvium exists, or has existed at some time during the past 20 years. The nature of this communication is not conclusively proven and the EPA has raised questions about the interpretation given in the Draft RI report.

The quantification of the effective communication between the upper alluvial zone and the lower aquifer zone is critical to the evaluation of remedial action plans for the site. In June, 1986, Applied Hydrology Associates (AHA) proposed a testing program to evaluate this communication. Resource Engineering Inc. (REI) were authorized by the French Limited Task Group to carry out the 1986 Field Investigation Program. AHA was retained by ARCO Chemicals to observe the drilling, well completion and hydrologic testing program; interpret the results; evaluate the degree of hydrologic communication between the shallow aquifer and the lower zone; determine the likely source of the limited contamination discovered in the lower zone and to provide a degree of independent oversight to this program.



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2.0 GEOLOGIC SETTING

The French Limited is located within the flood plain of the San Jacinto River. The stratigraphy of the site as depicted in Figure 2-1, can be divided into three zones: an upper predominantly sandy zone, a middle clayey zone and a lower silty-sand zone. Figure 2-1 shows the relative consistency of the these units at different locations within the general vicinity of the French Limited site.

2.1 UPPER ALLUVIAL ZONE

The upper zone is believed to represent deposits of the San Jacinto River and consists of poorly consolidated sands and silty sands with occasional clayey zones. The zone is water bearing and due to its sandy nature yields water easily to well. A geologic unit having these types of characteristics is generally termed an aquifer (Freeze and Cherry, 1979).

The upper alluvial zone is approximately 50 feet thick and tends to contain the coarsest sands and occasional gravels in the uppermost 20 to 30 feet. This uppermost coarse sandy unit has been interpreted as a recent alluvial deposit of an abandoned channel of the San Jacinto River and has been termed the French Limited Alluvium in previous RI reports. Earlier studies indicated that this upper coarse sandy unit thins towards the Riverdale subdivision. An erosional remnant of the earlier generally finer-grained alluvial deposits was interpreted as separating the French Limited Alluvium from the uppermost alluvial deposits in the vicinity of the subdivision which was was termed the Riverdale Alluvium. In this report the entire thickness of the alluvial deposits is treated as a single hydrogeologic zone.

2.2 MIDDLE CLAYEY ZONE

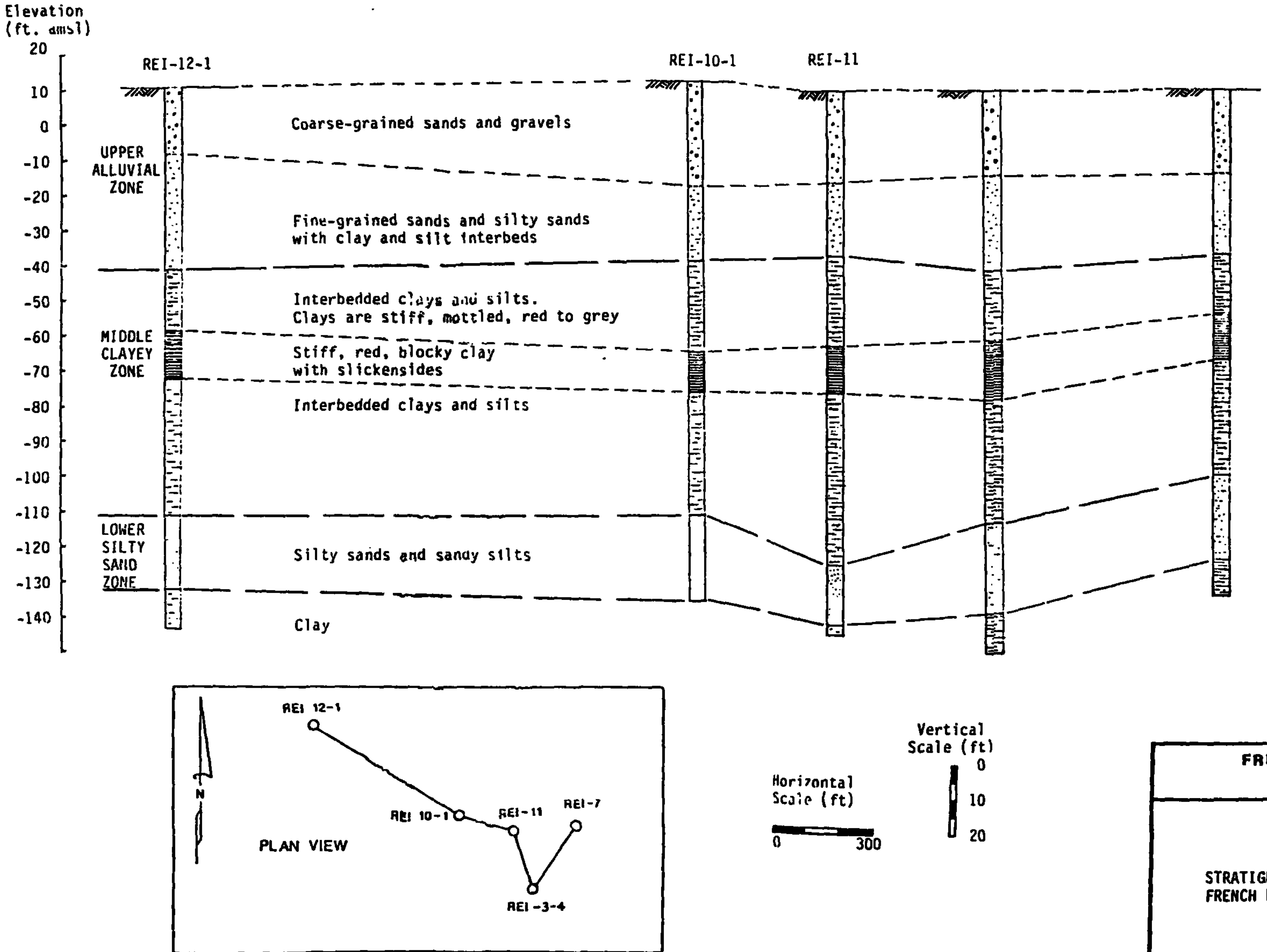
The middle zone consists of thinly interbedded silty clays and clayey silts of the Beaumont Formation. Some minor silty sand units are present in the lower part of the middle clayey zone in the eastern part of the study area in the vicinity of well REI-7. The rest of the zone is relatively uniform across the site. The zone is saturated but due to its clayey nature does not yield water easily to wells and tends to restrict the transmission of groundwater to adjacent aquifers. A geologic unit having these types of characteristics is generally termed an aquitard or an aquiclude depending on the degree of transmission (Freeze and Cherry, 1979).

The middle clayey zone is about 70 feet thick and contains a consistent 11 to 14 foot thick zone of stiff red clay at a depth of about 75 feet below ground level. The clays of this zone are characteristically reddish-brown or blue-grey with reddish mottling, blocky in texture and contain slickensides.

2.3 LOWER SILTY SAND ZONE

The lower zone is a poorly consolidated water bearing silty sand or sandy silt zone directly underlying the clayey middle zone. The zone yields water easily to wells and is considered to be an aquifer (Freeze and Cherry, 1979)

The lower silty sand zone varies in thickness from 15 to 30 feet. It tends to thin and contain more fines in the southern and eastern parts of the site based on conditions encountered at the REI-3-4 and REI-7 wells. It is bounded at its base by a silty clay unit having a thickness of at least five feet. This lower zone may represent a sandy zone within the Beaumont Formation or the upper part of the Lissie Formation which underlies the Beaumont.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 2-1

STRATIGRAPHIC CROSS-SECTION THROUGH FRENCH LIMITED SITE (NW to SE)

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3.0 RECOMMENDED WELL COMPLETION AND TESTING PROGRAM

In the Review of the French Limited Remedial Investigation prepared by AHA on June 5, 1986, a recommendation was made to conduct a hydrologic test in the vicinity of the GW-25 well in order to determine the pathways and magnitude of hydraulic communication between the lower silty sand zone and the upper alluvial zone. This location was suggested because of its close proximity to the lagoon and because contamination in the lower zone has been identified from samples taken from the lower zone well completed in the area.

A relatively long-term pump test was proposed for the lower zone with monitoring of responses in the overlying middle clay zone and upper alluvial zone. Additional recommended testing at the site included at least one and preferably two single-well response tests in the stiff clay layer of the middle clayey zone.

The initial recommended well layout required an additional lower zone well, three shallow wells completed in the lower part of upper alluvial zone and two piezometers completed in the lower and central parts of the stiff clay layer within the middle clayey zone. The testing program called for the new lower zone well to be utilized as the pumped well for the lower zone test and the existing GW-25 well to be used as a lower zone monitoring well. The number and locations for the upper alluvial zone wells were designed to evaluate the contention that existing deep wells and/or sand channels may be conduits for contaminant migration to the lower zone.

AHA recommended that the two clay piezometers be completed using 1-2inch ID pipe using similar techniques as recommended for the lower zone well. AHA proposed that the screened interval for the piezometer installations should preferably be drilled using auger or air-rotary techniques. Screened and sand-packed intervals for the piezometers were recommended to be about 2 feet in length. It should be noted that after completion of the lower zone well and examining aquitard characteristics, AHA recommended that a third piezometer be installed in the middle clayey zone just below the stiff clay layer in which the first two piezometers was installed.

Initial calculations assuming various values for the hydrologic properties of the upper and lower aquifer zones and the middle clayey zone indicated that the lower zone test should be conducted for at least six days. AHA also suggested that other factors that might influence well responses, such as barometric pressure, should be monitored during the test.

In response to the AHA Review Report (included in Appendix 1), EPA suggested using the ratio method of Neuman and Witherspoon (1972) for determining characteristics of the middle clayey zone. AHA concurs that this is one of the most appropriate analytical techniques presently available for determining characteristics of aquitards adjacent to aquifers. In fact, AHA used the ratio method of Neuman and Witherspoon (1972) as the basis for design of the testing program. In discussions with Neuman he has indicated that the primary limitation in applying the technique is that the lower zone response to pumping used in the analysis should be attributable only to pumping of the test well. Other influences on lower zone water levels have to be factored out of the analysis.

On July 8, prior to commencement of drilling, a field visit was conducted with representatives of AHA, REI, EPA and the French Limited Task Group. Well and piezometer locations were marked in the field. Two additional lower zone wells were included in the program to better characterize the hydrogeology of this aquifer. The agreements reached concerning well locations and testing procedures are described in a letter from AHA to Richard L. Sloan dated July 10. 1986 and included in Appendix 1.

4.0 DRILLING AND WELL COMPLETION PROGRAM

AHA observed and monitored a considerable portion of the drilling and most of the well completions associated with the 1986 Field Investigations. The well completion descriptions together with any problems or difficulties encountered during well completion and development are discussed in Appendix 2. No significant problems were encountered during drilling and well completion which might impact the test design. A slight problem in placing the sand pack around the screened interval of the clay piezometer P-10-3 was noted and considered in all data interpretation.

Coordinates and elevations of top of well casings were surveyed for all new wells and several existing wells. Survey data and well completion logs for the 1986 wells developed by REI are included in Appendix 2. Locations of monitoring wells installed or used during the 1986 field program are provided in Figure 4-1. A detailed illustration of well locations at the REI-10 well cluster is provided in Figure 4-2.

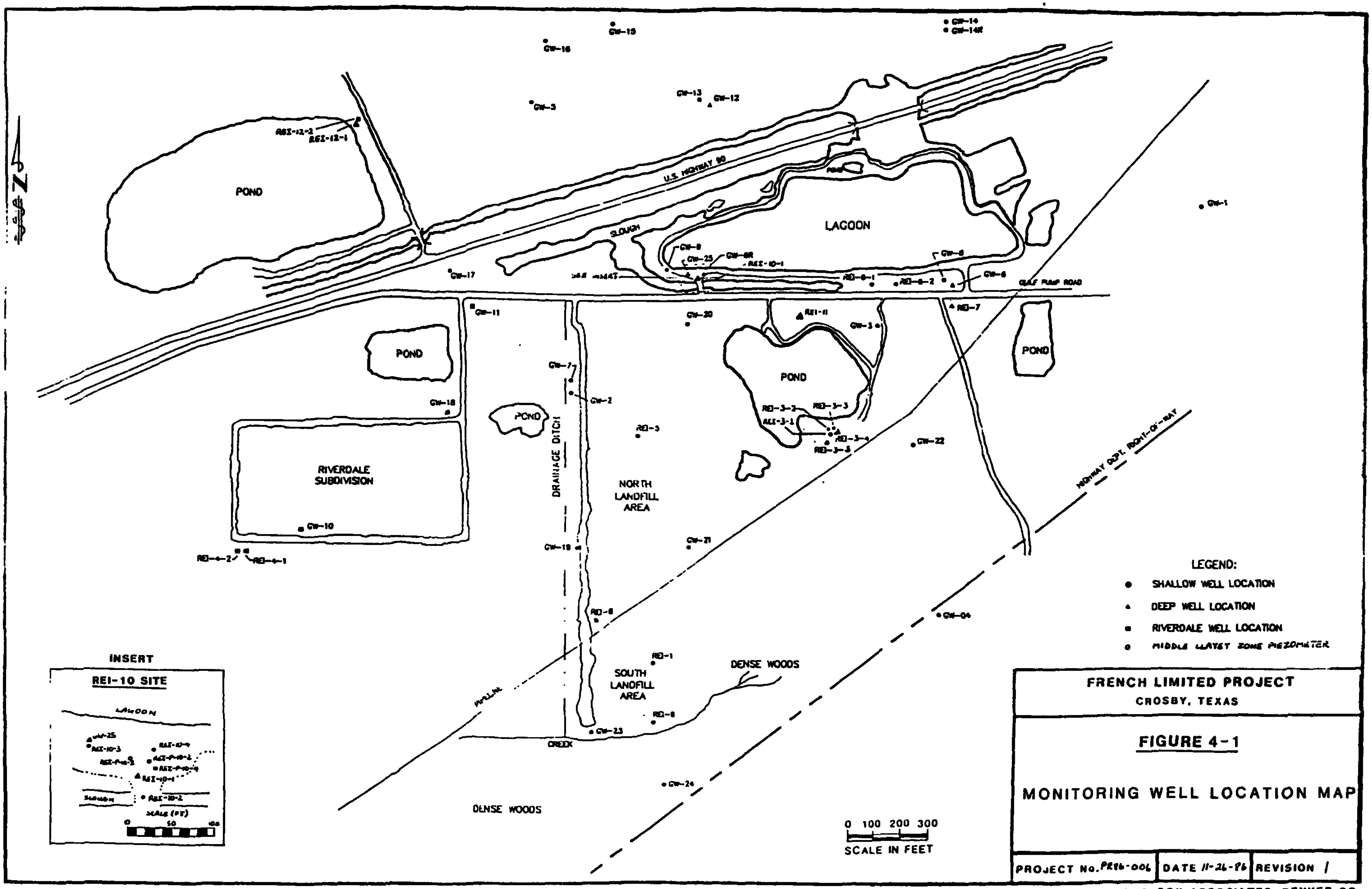

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FIGURE 4-1

MONITORING WELL LOCATION MAP

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

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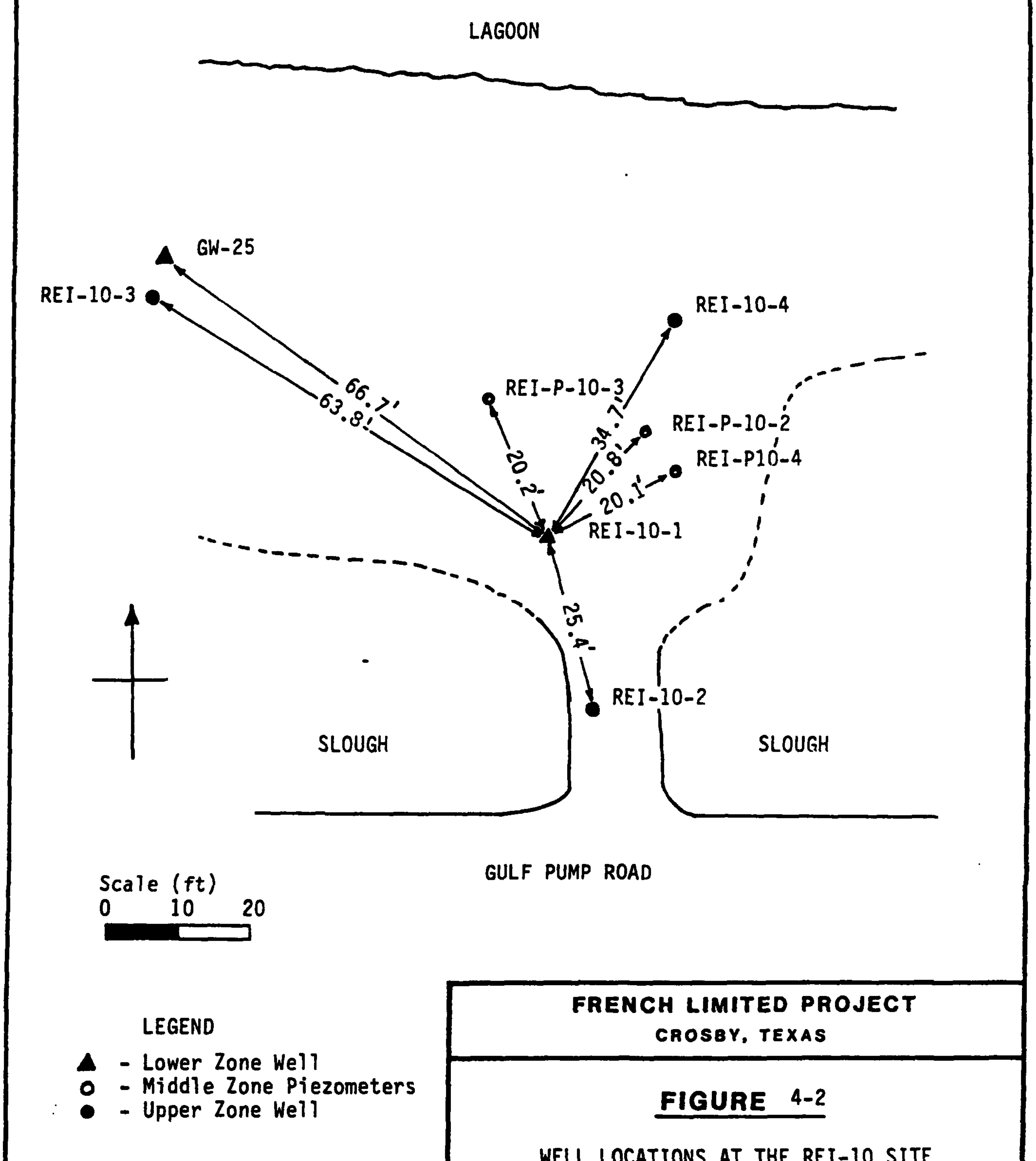

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CROSBY, TEXAS

FIGURE 4-2

WELL LOCATIONS AT THE REI-10 SITE

PROJECT No. PR86-006	DATE 12-1-86	REVISION 1

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5.0 HYDROGEOLOGIC DESCRIPTION

5.1 APPROACH AND FUNDAMENTAL CONSIDERATIONS

The approach followed in developing an understanding of the hydrogeology of the French Limited Site was to rely on extensive observations and to objectively consider and analyze alternative explanations for the observed behavior. Only after all the evidence is examined and interpreted and all the questions concerning the observations are answered to the satisfaction of the hydrologist is it possible to develop logical conclusions needed to support the development of remedial action alternatives. De Wiest (1986) compares the approach to hydrologic investigations with the approach taken in modern medicine. Both medicine and hydrology are studies in observation. Successful practitioners in both fields learn "to make a diagnosis, after analysis of all differential diagnoses, after laborious scrutiny."

In this study, the primary interest is in determining the characteristics of the various geologic units that determine the pathways and rates of possible contaminant migration in the groundwater system in the vicinity of the French Limited Lagoon. This requires information on the nature and continuity of geologic units, the permeability, porosity, and elastic storage characteristics of these units and the energy state of water or potentiometric heads that represent the driving force for groundwater (and contaminant) movement. Quantification of these characteristics is necessary to evalate and predict the hydrologic and contaminant migration consequences of various remedial action alternatives.

The direction and volumetric rate (specific discharge or flux) of groundwater flow normally follows Darcy's law:

$$q = KI = K\,dh/dl \qquad (5\text{-}1)$$

where:

q = volumetric flow rate per unit area [L/T]

K = hydraulic conductivity [L/T]

$I = dh/dl$ = potentiometric head gradient [dimensionless]

The hydraulic conductivity is a measure of the capability of a porous medium to transmit water. The intrinsic permeability is a more fundamental parameter of a porous medium as it is independent of the fluid. It is related to hydraulic conductivity by:

$$K = kpg/u \quad \text{.............................} (5\text{-}2)$$

where:

K = hydraulic conductivity [L/T]

k = intrinsic permeability [L^2]

p = density of the fluid [M/L^3]

g = acceleration due to gravity [L/T^2]

u = viscosity of the fluid [M/TL]

It is also important to realize that the hydraulic conductivity can vary spatially (homogeneity) and directionally (anisotropy.) Typically the hydraulic conductivity of sedimentary deposits is an order of magnitude lower in the vertical direction than in the horizontal direction.

Groundwater actually moves through the intersticies of a porous medium. The pathways may be between the grains of unconsolidated materials or through secondary openings such as fractures in consolidated materials. The average velocity of groundwater flow is generally related to the flux by:

$$v = q/n = KI/n \quad \text{..............................} (5\text{-}3)$$

where:

v = groundwater velocity [L/T]

q = groundwater flux [L/T]

n = effective porosity of the medium [dimensionless]

The effective porosity is considered to be that part of the total porosity of the medium that is significant with respect to fluid flow. In evaluating the movement of contaminants in groundwater systems it is usually both the actual velocity of groundwater flow and the flux which is of interest. Contaminants usually move through the groundwater system at a lower velocity than the groundwater itself due to retarding processes which result from interaction with the material of the porous medium. However, the velocity of groundwater flow is a conservative estimate of the rate of contaminant transport in groundwater flow systems. The groundwater flux is of interest in contaminant studies as, for a given concentration of contaminant, this is a conservative measure of the quantity of contaminant moving through the system per unit time.

5.2 HYDROGEOLOGIC CHARACTERISTICS OF THE GROUNDWATER FLOW SYSTEM

5.2.1 Upper Alluvial Zone

The upper alluvial zone contains relatively high permeability gravels and sands with occasional clayey units. Groundwater exists under primarily unconfined conditions within this zone. The water table occurs very close to ground surface in most areas of the site and is close to the water levels of adjacent ponds. Water level fluctuations in wells completed in this zone respond to precipitation and evapotranspiration influences as indicated by observations preceding and during the pump testing program.

The increase in groundwater levels in the upper alluvial zone following significant precipitation events is believed to represent recharge to the zone both through direct infiltration and via surface water bodies. Comparison of precipitation measurements, the French Limited lagoon water level fluctuations, and shallow alluvial well water level fluctuations (Figure 5-1) for the same time period yields insight into the nature of the recharge at the REI 10 well site. Water levels in the alluvial wells rise rapidly in response to the start of the precipitation event, typically within 30 to 50 minutes. A lag time period of 200 to 500 minutes between the end of the precipitation event and the end of alluvial water level rise also appears in the response to precipitation illustrated in Figure 5-1.

The influence of evapotranspiration on alluvial groundwater levels is readily observable in the hydrographs of the upper alluvial wells during periods of little or no precipitation (Figures 5-2, 5-3, and 5-4). Water level drops of several hundredths of a foot are apparent in the alluvial wells between the night hours and the middle of the day, particularly on clear sunny days. Barometric influences are not apparent as might be expected for unconfined conditions.

Potentiometric head variation with depth and response characteristics within the upper alluvial zone suggest that the interbedded clay units within the this zone do not significantly restrict the vertical communication through the zone in the vicinity of the French Limited lagoon. Wells completed at the basal sections of the upper alluvial zone at the REI-10 site have levels very similar to water table levels and respond to recharge and evapotranspiration influences which directly effect the near surface alluvial groundwater. These observations are consistent with the existence of reasonably good vertical communication within the upper alluvial zone at this site.

Water level readings in wells completed in the upper alluvial zone within several distinct sandy units separated by clays at the REI-3 well site indicate a slight upward component of the hydraulic gradient averaging about 0.008 ft/ft. This does indicate some confining characteristics within the upper alluvial zone in this location. Small differential variations in water levels in the wells due to influences described above cause the magnitude of this upward component to vary slightly but the overall head rise with depth through the zone averages about 0.3 feet. Hydrogeologic investigations summarized in the Draft RI Report indicate that pumping of one well at the REI-3 site caused water level responses in the other wells indicating reasonably good hydrologic communication within the upper alluvial zone at this site.

The lateral potentiometric distribution within the upper alluvial zone varies significantly in the vicinity of the French Limited site and this probably reflects regional groundwater flow within the zone as well as the influence of local surface water bodies. The geologic investigations of the RI report identified a high sand content trend in shallow subsurface that is interpreted as a recent abandoned channel of the San Jacinto River. The potentiometric surface has been interpreted in the RI to follow this trend on a regional basis but may be influenced locally by surface water bodies. Since most of the alluvial wells are close to surface water bodies it is difficult to distinguish between local and regional effects. Water level elevations in wells completed at the base of the upper alluvial zone at the REI-10 and REI-3 sites indicate a lateral hydraulic gradient between the sites in the order of 0.002 ft/ft. The local hydraulic gradient in the vicinity of the REI-10 site based on water levels in the REI 10-2, 10-3 and 10-4 wells is to the south-south-east at about 0.002 ft/ft. This slight gradient away from the lagoon suggests that recharge from the lagoon is at a very slow rate.

The upper alluvial zone has good hydrogeologic continuity and relatively high permeabilities within the sandy units of the zone which result in reasonably good water yields to wells. It is therefore reasonable to consider the zone as a single hydrogeologic unit and based on relative water-yield characteristics would be considered an aquifer in this area. The aquifer is unconfined but may display confined characteristics locally where significant clay lenses exist within the zone.

5.2.2 Middle Clayey Zone

The middle clayey zone consists of low permeability clays and silts which do not yield significant quantities of water to wells installed in this zone. Field and laboratory tests described latter in this report confirm the generally low permeability of the clay and silt units. The apparent lateral consistency of the zone in the vicinity of the French Limited site, the predominance of fine-grained materials and the observation of large potentiometric differences across the zone indicates that the zone is an effective barrier to downward migration of groundwater and acts as a confining layer for the underlying lower silty sand zone.

The middle clay zone has been referred to as an aquitard in the regional groundwater system. AHA's analysis of the 1986 field tests as explained in this report, indicates that the unit should more appropriately be referred to as an aquiclude because it is "incapable of transmitting significant quantities of water under ordinary hydraulic gradients" (Freeze and Cherry 1979). During the review of the Draft RI Report, concerns were raised about the effectiveness of the middle clayey zone as a barrier to downward migration of groundwater due to evidence of contamination in the GW-25 well completed below the zone. Part of the 1986 field program was designed to evaluate the vertical hydrologic characteristics of the middle clayey zone and the cause of contamination observed in the lower silty sand zone in samples taken from well GW-25.

Wells completed above, below and within the middle clayey zone at the REI-10 site indicate that the zone is completely saturated and shows a drop in potentiometric head across the unit of approximately 76 feet (Figure 5-5). This is equivalent to an average vertical hydraulic gradient of about 1.0. Prior to extensive pumping of deeper confined regional aquifer units, the vertical head gradients were probably quite low, as lower zone heads were likely above sea level and head levels in the alluvial aquifer were close to land surface. Extensive pumping has resulted in considerable drawdown of potentiometric heads in confined units. The low permeability in the middle clayey zone has allowed heads in the upper alluvial zone to remain close to the surface despite the very significant head drops in the underlying aquifers.

A consistent stiff clay unit ranging from 11 to 14 feet in thickness within the middle clayey zone was previously identified in the Draft RI to be a particularly effective confining unit. It is interesting to note that the potentiometric gradient across the stiff clay unit is about the same as the overall gradient across the middle clayey zone (Figure 5-5). This suggests that the resistance to vertical groundwater flow across the stiff clay is about the same as average resistance to flow across the middle zone as a whole. This is not surprising as the average vertical permeability of the interbedded silt and clay units within the zone will tend to be dominated by the lower permeability clay units (Freeze and Cherry, 1979). The significance of the stiff clay unit is based on its continuity throughout the area. However, the nature of the potentiometric variation with depth shown in Figure 5-5 suggests that the entire middle clayey zone acts as a confining unit in the vicinity of the French Limited Lagoon.

The water level fluctuations observed in the clay and silt piezometers reflect the potentiometric response of the clay and silt units within the middle zone to imposed stresses on the geologic system. Stresses may be imposed naturally, for example as a result of extensive blanket loads such as precipitation or changes in atmospheric pressure. Stresses may also be induced artificially as a result of pumping from an aquifer unit above or below the middle clayey zone. Observations of water level fluctuations in the silt and clay piezometers of the middle clayey zone during the pump testing program, described in more detail in Section 6 of this report, indicate no apparent response to changes in barometric pressure but rapid response to loadings induced by significant precipitation events (Figure 5-1). The precipitation effect may be enhanced by the existence of numerous surface water bodies which may receive surface runoff during high precipitation events.

The significant response of the middle clayey zone to precipitation loadings was not anticipated prior to testing. The phenomenon is documented in the literature primarily in relation to blanket loads associated with tidal fluctuations (Domenico, 1972; Todd 1959). The lack of barometric response and the extremely efficient response to blanket precipitation loads can be explained by the presence of an extensive confining unit of very low permeability that prevents vertical drainage of pore water. A detailed explanation of the blanket precipitation load response is provided in Section 5.3.

Standard consolidation tests were performed on three core samples of the stiff clay unit to evaluate compressibility characteristics and intergranular hydraulic conductivities. The main purpose of the tests were to calculate specific storage values for the clay unit (Domenico, 1972). These values could then be used in the analysis of potentiometric responses of this unit to imposed stresses to evaluate field hydraulic conductivities. Comparison of field and laboratory hydraulic conductivity values will indicate whether this characteristic is significantly influenced by secondary features such as slickensides.

The results of the consolidation tests are summarized in Table 5-1. Raw data are included in Appendix 3. Calculated specific storage values varied from 2×10^{-6} to 4×10^{-6} cm^{-1}. Hydraulic conductivity values were calculated from the consolidation tests using a method described by Seaber and Vecchioli (1966). These values are consistent with laboratory values calculated from falling head permeameter tests previously reported in the RI. Hydraulic conductivity ranges from 1.23×10^{-9} to 2.05×10^{-10} cm/sec which is typical of intergranular values for clays (Freeze and Cherry, 1979).

5.2.3 Lower Silty Sand Zone

The lower silty sand zone is a confined saturated unit which may be correlated across the French Limited site. It is the first significant sandy unit underlying the middle clayey zone. The water yielding characteristics of the zone appear to vary in response to variations in thickness and silt content within the zone. Hydraulic characteristics of the zone calculated from pumping tests are discussed in detail in later sections.

The water level fluctuations observed in the lower silty sand zone respond to pumping within the zone and to blanket loads imposed by significant precipitation as represented by well REI-11 (Figure 5-1). As is the case in the middle clayey zone, the water level fluctuations in the lower silty sand zone indicate no response to changes in barometric pressure. The lack of barometric response and the extremely efficient response to blanket precipitation loads as explained in Section 5.3 indicates the presence of an extensive confining unit of very low permeability that prevents vertical drainage of pore water. It also demonstrates the lack of permeable sand channels connecting the zone with the upper alluvial zone.

Potentiometric variation within the lower zone based on water level elevations in six observation wells indicates a general eastward hydraulic gradient of about 0.001 ft/ft (6.3 ft/mile).

5.3 RESPONSE TO EXTERNAL BLANKET LOADS

Water level response to external blanket loads such as tidal fluctuations, atmospheric pressure changes or precipitation events may be explained by Terzaghi's classical theory of consolidation (Terzaghi and Peck, 1967). An induced loading or change in total stress, dP, on a saturated porous medium is accommodated by corresponding changes in pore water pressure, dPw and intergranular pressures or effective stress, dPm. This may be represented as:

$$dP = dPw + dPm \quad \ldots\ldots\ldots\ldots\ldots\ldots (5\text{-}4)$$

If the intergranular matrix is incompressible then the blanket load is taken up by the intergranular pressures and there is no change in pore water pressures. If the intergranular matrix is more compressible than water, then the increase in total stress is taken up both by increases in pore water pressure and by increases in effective stress. In this situation, the increased intergranular stress (change in effective stress) is only

TABLE 5-1

RESULTS OF CONSOLIDATION TESTS PERFORMED ON SAMPLES OF THE STIFF CLAY UNIT

SAMPLE	PRESSURES kg/cm^2		VOID RATIO			COEFFICIENT OF COMPRESSIBILITY cm^2/kg	COEFFICIENT OF CONSOLIDATION in^2/day	HYDRAULIC[(1)] CONDUCTIVITY cm/sec	SPECIFIC[(2)] STORAGE cm^{-1}
	init	final	init.	final	aver.				
REI P10-4	2	4	0.773	0.766	0.770	0.0035	6.594	$9.72x10^{-10}$	$1.98x10^{-6}$
81-82 ft	4	8	0.766	0.747	0.757	0.00475	4.836	$9.71x10^{-10}$	$2.70x10^{-6}$
	8	16	0.747	0.703	0.722	0.00550	2.452	$5.76x10^{-10}$	$3.20x10^{-6}$
	16	32	0.703	0.612	0.658	0.00569	0.824	$2.05x10^{-10}$	$3.40x10^{-6}$
REI P10-4	2	4	0.873	0.869	0.871	0.002	7.162	$5.71x10^{-10}$	$1.10x10^{-6}$
80-81 ft	4	8	0.869	0.844	0.857	0.0063	2.129	$5.44x10^{-10}$	$3.40x10^{-6}$
	8	16	0.844	0.789	0.817	0.0068	1.388	$3.96x10^{-10}$	$3.70x10^{-6}$
	16	32	0.789	0.716	0.753	0.0046	1.186	$2.31x10^{-10}$	$2.60x10^{-6}$
REI P10-4	2	4	0.818	0.816	0.817	0.0009	10.615	$4.24x10^{-10}$	$0.50x10^{-6}$
81-82 ft	4	8	0.816	0.798	0.807	0.0045	6.502	$1.23x10^{-10}$	$2.50x10^{-6}$
	8	16	0.798	0.756	0.777	0.0053	2.659	$5.93x10^{-10}$	$3.00x10^{-6}$
	16	32	0.756	0.683	0.72	0.0046	1.71	$3.42x10^{-10}$	$2.70x10^{-6}$

(1) Hydraulic conductivity, $K = C_v*p*g*A_v$

where: p = density

g = acceleration due to gravity

C_v = coefficient of consolidation

A_v = coefficient of compressibility

(2) Specific Storage, $S_s = (A_v*p*g) / (1+e)$

realized if pore water escapes from the compressed unit allowing the matrix to compress.

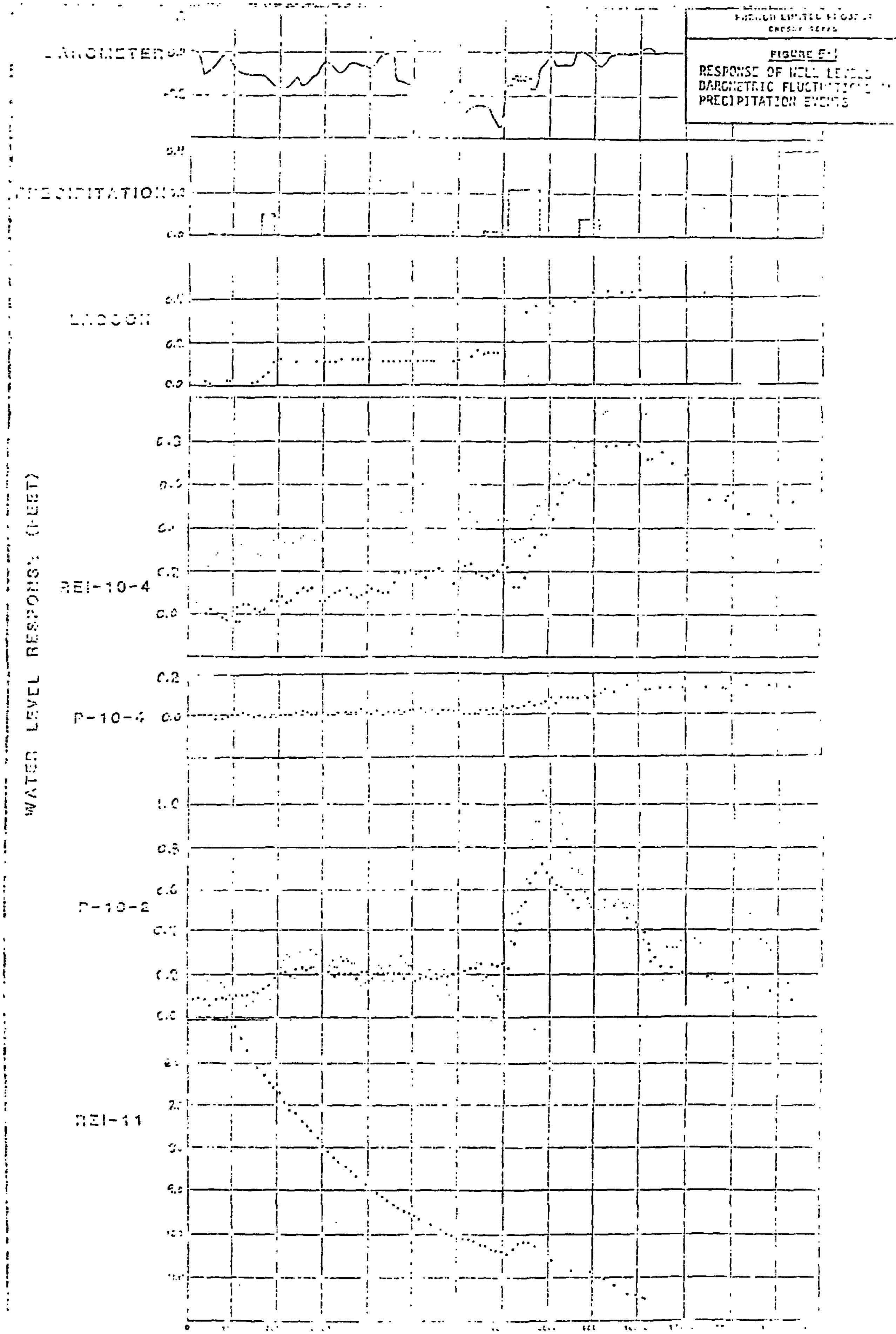
Thus the pore pressure response in confined units to blanket precipitation loads should be almost immediate. If water cannot drain in response to pore pressure increases, then a pore pressure response nearly equivalent to the increased total stress will be sustained.

The widespread, relatively uniform loading which accompanies a significant precipitation event would not tend to induce lateral or vertical pore pressure differentials that would cause rapid drainage within any individual unit. In this situation, pore pressure relief can be achieved if an external drainage mechanism is effective. For example, this could be achieved via downward vertical drainage to an underlying zone that was being actively pumped or via upward vertical drainage to the overlying unconfined aquifer. As demonstrated in section 6.4, pore water pressures did not decline in the silt unit piezometer P-10-2 following blanket precipitation loads except towards the end of the 7-day pumping test of the lower aquifer zone when pumping started to have a draining influence in the lower part of the middle clayey zone. This demonstrates that the silt unit is confined by extensive low permeability units that prevent the upward vertical drainage of pore water.

The water levels in the lower silty sand zone wells and middle clayey zone piezometers did not show any significant response to barometric fluctuations. The lack of barometric influence in these confined zones indicates that stress imposed by barometric pressure changes is compensated predominantly by pore pressure changes and not by changes in effective stress (intergranular pressures). In this case, the atmospheric pressure changes imposed directly on the standing column of water in a well produce nearly identical changes in pore water pressure in the geologic unit in which the well is completed. Consequently no barometric pressure response is seen since there is no pressure differential to induce movement towards or away from the well.

The nearly identical pore pressure response to changes in total stress was apparent not only from the lack of a barometric response but also from the response to blanket loads imposed by significant precipitation events observed during the 7-day pumping test at well REI-10-1 and during the second pump test at well REI-3-4.

Water levels in a well completed in a confined unit will rise in response to an imposed pressure differential between the confined unit and the well until a new equilibrium is reached. Thus, there will be a response lag between the changes in pore water pressure in the confined unit and the response recorded by water levels changes in standpipe piezometers and wells due to well bore storage effects. This lag in the response was observed in both the silt and clay piezometers within the middle zone during the long term REI 10-1 pump test. Even though the piezometer installations in the middle zone used small diameter pipe to minimize these effects, the permeability of the clays are sufficiently low that there is a significant lag in the piezometer response. This lag in piezometer response was used in Section 6 to estimate horizontal permeabilities in the clay and silt units.



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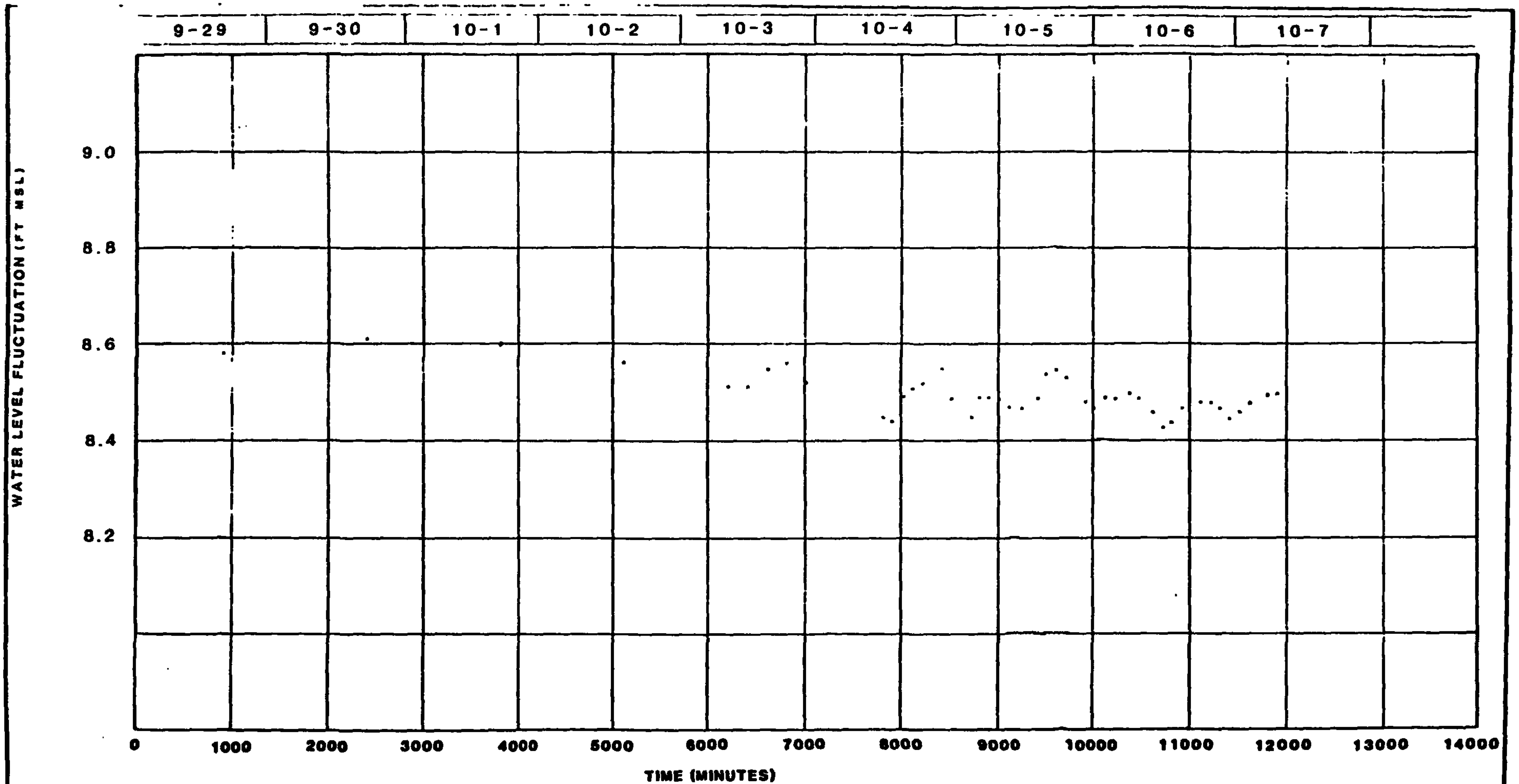

LEGEND

• MANUAL DATA

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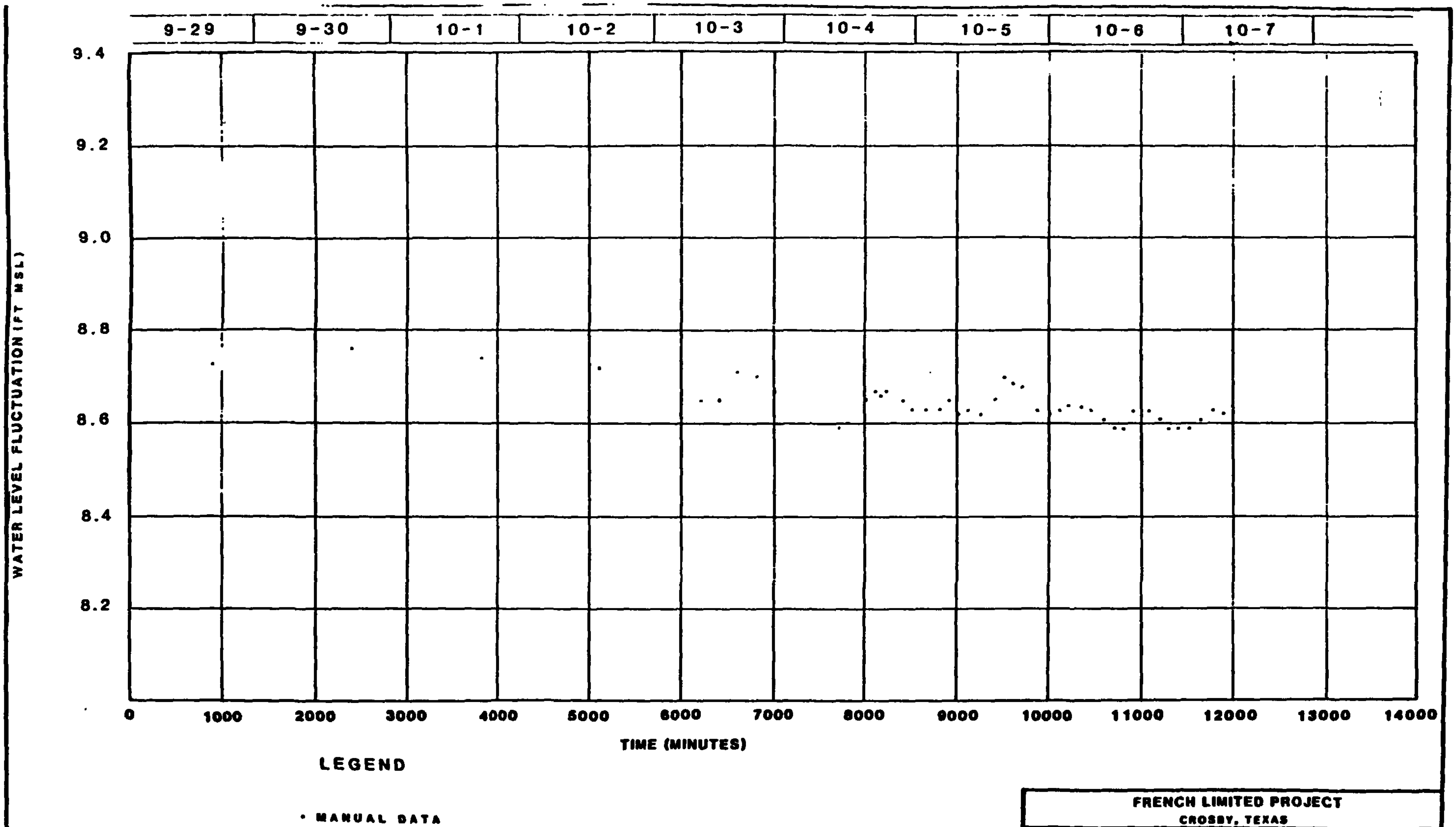
FIGURE 5-2
WATER LEVEL RESPONSE PLOT
OBSERVATION WELL: REI 10-2 PUMPED WELL: PRE-TEST
DATE(S): 9/29/86 to 10/7/86 COMMENTS:

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



FRENCH LIMITED PROJECT
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FIGURE 5-3
WATER LEVEL RESPONSE PLOT
OBSERVATION WELL: REI 10-3 PUMPED WELL: PRE-TEST
DATE(S): 9/29/86 to 10/7/86 COMMENTS:

PROJECT No. PRFL-006 | DATE 11-26-86 | REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.

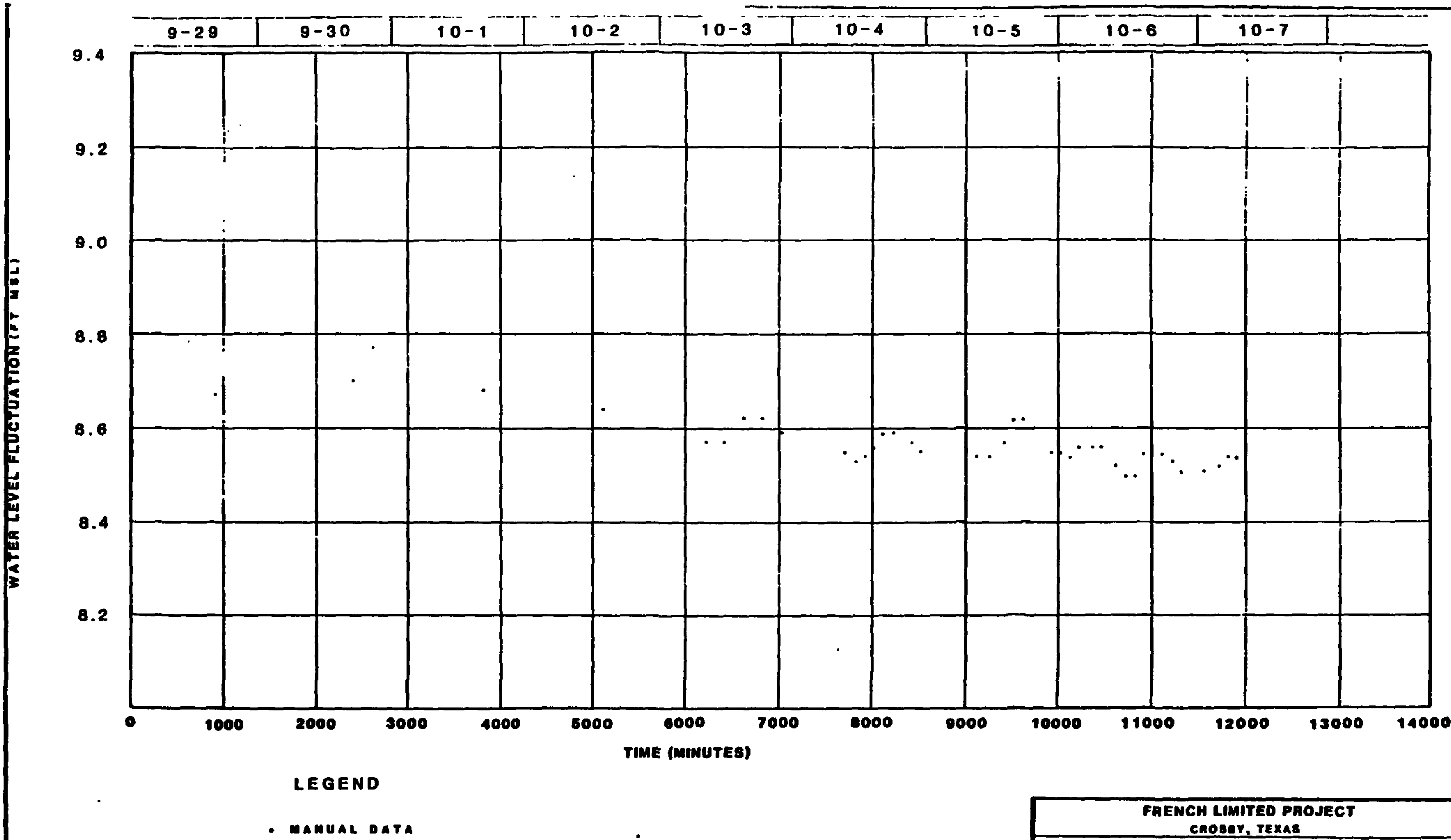

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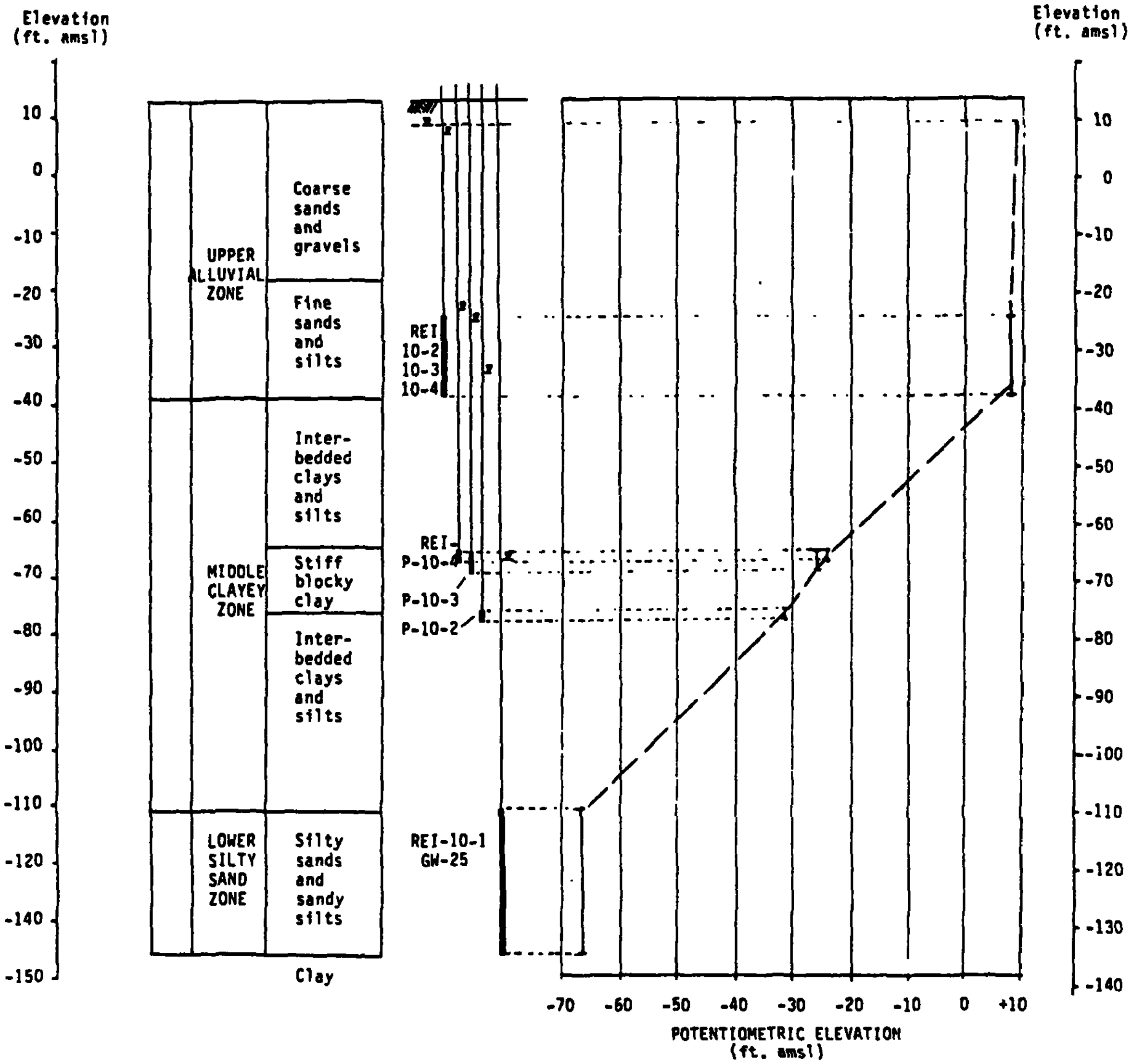
FIGURE 5-4
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 10-4 PUMPED WELL: PRE-TEST
DATE(S): 9/29/86 to 10/7/86 COMMENTS:

PROJECT No. PRFL-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 5-5

POTENTIOMETRIC VARIATION WITH DEPTH AT THE REI-10 SITE (October, 1986)

PROJECT No. PR-006	DATE 11-11-8	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.

6.0 HYDROLOGIC TESTING PROGRAM

Following completing the installation of monitoring wells, pump testing programs were implemented to determine aquifer and aquitard characteristics. A schedule showing the sequence of pump tests performed as part of the 1986 Field Program is provided in Table 6.1.

6.1 PUMP TESTING OF WELL REI-3-3 (August 11)

The first test was performed on the upper part of the upper alluvial zone aquifer at well REI 3-3. This well was tested previously in November, 1985 with results provided in the Draft RI Report. Questions were raised about the method of interpretation and the number of monitoring wells required for interpretation. An additional observation well REI-3-5 was completed during the 1986 field program and a new pump test was performed. The initial plan was to use the new well, REI-3-5 as the pumped well. The well did not produce enough to run a sustained pump test. Consequently, REI-3-3 was selected as the pumped well.

The REI-3-3 well was pumped at a fairly steady rate of 3.0 gpm for 750 minutes. A slightly higher pumping rate of 3.2 to 3.4 gpm was recorded about 50 minutes into the test. Water levels in the pumped well and two observation wells, REI-3-5 and an un-numbered piezometer, were monitored manually using conventional well sounders. Measurement accuracy is about +/- 0.02 feet. The water level response of the three wells during the drawdown portion of the test is shown in Figures 6-1, 6-2 and 6-3.

The water level drop noted in all wells after about 50 minutes probably reflects the adjustment of pumping rate noted above. The flattening of the water level response observed in all wells following this drop is believed to be attributable both to the onset of delayed yield effects (Boulton, 1963) and recharge effects from an adjacent pond about 70 feet from the pumping well. It is difficult to isolate the effects of these two influences.

The most reliable part of the test for analysis of hydrogeologic characteristics is the early time data prior to the noted increase in pumping rate and also before the onset of recharge or delayed yield effects. Analysis of the responses in the two observation wells were performed using the type-curve match method described by Boulton (1963) developed for non-steady state response to pumping in unconfined aquifers. Actually, for early time matches before the onset of delayed yield effects the Boulton type curves are identical to the Theis (1935) type curve. The analysis indicates a transmissivity for the uppermost part of the upper alluvial zone of about 500 gpd/ft (0.72 cm^2/sec). For a saturated thickness of about 19 feet, an average hydraulic conductivity of about 1.2×10^{-3} cm/sec is indicated for this unit. The storage coefficient calculated for the unit is about 0.003 which is reasonable for unconfined aquifer units (Freeze and Cherry, 1979).

TABLE 6-1

PUMP TEST CHRONOLOGY & DESCRIPTION

PUMPED AQUIFER	PUMPED WELL	DATES	DURATION DRAWDOWN TEST	DURATION RECOVERY TEST	PUMPING RATE (GPM)	OBSERVATION WELLS
UPPER ALLUVIAL ZONE	REI-3-3	8/11 TO 8/12	885 MIN	135 MIN	3.0	REI-3-3,REI-3-5& REI-P-3-3
LOWER SILTY SAND ZONE	REI-10-1	8/16	89 MIN	----	8.0	GW-25
	REI-3-4	8/20 TO 8/21	360 MIN	810 MIN	1.5 TO 2.5	REI-3-4,REI-7,REI-10-1,REI-11 REI-3-3,REI-3-2,REI-3-1
	REI-3-4	8/21 TO 8/25	4350 MIN	955 MIN	1.1 TO 1.9	REI-3-4,REI-7,REI-10-1,REI-11 REI-3-3,REI-3-2,REI-3-1
	REI-10-1	9/15 TO 9/19	1650 MIN	3787 MIN	12 TO 20	REI-10-1,REI-11,REI-7,REI-10-2 REI-10-3,REI-10-4,REI-3-4,GW-25 REI-12-1,P-10-2,P-10-3,P-10-4
	REI-10-1	9/19 9/19	220 MIN	25 MIN	VARIABLE	REI-10-1,REI-11,REI-10-2 REI-10-3,REI-10-4,REI-3-4,GW-25 P-10-2,P-10-3,P-10-4
	REI-10-1	10/7 TO 10/17	10210 MIN	4315 MIN	15 TO 18	REI-10-1,REI-11,REI-7,REI-10-2 REI-10-3,REI-10-4,REI-3-4 REI-12-1,P-10-2,P-10-3,P-10-4
MIDDLE CLAYEY ZONE	P-10-3	11/3 TO 12/3	-------	30 DAYS	SLUG	P-10-3
	P-10-4	11/3 TO 12/3	-------	30 DAYS	SLUG	P-10-4

6.2 PUMP TESTING AT WELL REI-3-4 (August 20 to 25)

The initial pump test of well REI-3-4, completed in the lower silty sand zone, was started on August 20, 1986. Simultaneous water level measurements were taken using a pressure transducer/data logger system to record water levels in the alluvial aquifer observation wells at the REI-3 well cluster and at the lower zone wells, REI-11, 7, and 10-1 during the test. This allowed a detailed record of water level variations to be maintained. Transducer measurements were checked with periodic manual measurements. AHA's observation of manual well sounding procedures used during this test and subsequent pumping tests at the REI-10 well cluster, leads us to believe that the manual measurements were usually quite reliable.

The pumping rate during the test was to be maintained at a preselected rate of 2.5 gpm. The initial pumping rate could not be maintained after about 15 minutes into the test. Because of the varying pumping rate it was decided to terminate the test and conduct a constant rate pumping test once the water levels had recovered. The initial test was not terminated quickly but continued for about 6 hours in an effort to determine a pumping rate that could be sustained and still produce substantial drawdowns. A pumping rate of 1.6 gpm was selected and the second test was started at 16:30 on August 21, 1986.

Plots of water level fluctuations in select wells during this test are provided in Figures 6-4 and 6-5. Comparison of transducer water level measurements with manual measurements taken with a well sounder indicate good agreement for measurements close to the initial levels. Differences between the transducer and manual measurements appear as levels changed from the initial level by several tenths of a foot. This may indicate a slight calibration problem in some of the transducers.

Interpretation of test data was made using traditional hydrologic methods for nonsteady state conditions. The response data from observation wells REI-11, REI-10-1 and REI-7, completed in the lower silty sand zone, are plotted in log-log format in Figures 6-6, 6-7 and 6-8. Match points for both the Theis Curve and the Type Curves of Black and Kipp (1977) are shown on the plots. The Black and Kipp type curves take into account the lag in observation well response due to well loss and well bore storage effects.

Conventional pump test analysis methods assume certain idealized conditions within the well and aquifer. Rarely are these conditions met in the application of these methods. Fortunately, reasonable estimates can be derived as long as the underlying assumptions are not severely violated. The estimates are more reliable the closer the hydrogeologic environment approaches the idealized conditions assumed by the methods

The results from the analyses of the latter portion of the recovery response in well REI-3-4 are thought to conform most closely to the assumptions underlying the use of pump test analysis methods. Well bore storage effects were minimal after about 70 minutes into the recovery period. The semi-log plot of recovery in the pumped well REI-3-4 is provided in Figure 6-8a. The semi-log analysis technique of Jacob (1940) was applied to the recovery response beyond 70 minutes into recovery. The estimated transmissivity was similar to estimates derived from the Theis analysis of responses in observation wells REI-10-1 and REI-11. (Table 6-2)

The drawdown response in the pumped well REI-3-4 was not analyzed because only the early portion of the test data was available. After about 2 hours water levels dropped below the transducer and a manual well sounder would not go down the well casing with the pump column and transducer cables in place. The analysis of the early test data was deemed to be pointless because well bore storage effects had a pronounced effect on the pumped well response during the early part of the test.

The analysis of the observation wells REI-10-1 and REI-11 are also believed to conform reasonably well with the assumptions underlying the use of the pump test analysis methods. The resulting transmissivity and storage coefficient values provided in Table 6-2 are also considered to be the representative of the lower silty sand zone in the vicinity of the REI-3-4 well. However, even these results must be interpreted with some caution because of the large distances from the pumped well and the inherent variability of hydrogeologic characteristics of the lower silty sand zone. The two pump test analysis methods applied to the the two observation well responses produced similar results considering the general order of accuracy of the methods.

The analysis of the response in well REI-7 was also deemed to be pointless because the inherent assumptions underlying the use of the pump test methods were severely violated. There is a considerable lag in the response in well REI-7 to pumping the REI-3-4 well. This lag occurs because of poor hydraulic communication between the completion interval of the two wells. Consequently, the use of conventional pump test analysis methods on the response in the REI-7 well yields an unreasonable value for aquifer transmissivity.

Observations of water level responses in the upper alluvial zone wells during the REI-3-4 test are provided in Figure 6-5. Diurnal fluctuations are most pronounced in well REI-3-3, the shallowest alluvial well. These fluctuations are damped in well REI-3-2, the middle well completed in the alluvium and are further damped in well REI-3-1, the deepest alluvial well. Water levels typically decline during the day in response to evapotranspiration reaching a minimum level at about 8 PM, Central Daylight Time. These water levels also track the relative humidity curve. When relatively humidities are below about 90% the water levels drop, above 90% the water levels appear to recover. On August 23, the water levels in the alluvium continued to rise and did not drop during the day. This rise is due to precipitation and high relative humidity on the 23rd. The blanket precipitation loading response described in Section 5.3 does not appear in the alluvial wells because the lower alluvial zones are apparently not tightly confined. Instead there is a damped response in the deeper units within the alluvium in response to level changes in the water table reflected in the measurements from well 3-3.

On the other hand, water levels in the three lower zone wells, REI-10-1, REI-3-4 and REI-11 did respond to the large precipitation event starting about 6 am on August 23 at 2300 minutes into the test. Field notes show that intense rainfall started about 7:30 on August 23. Intermittent intense

TABLE 6-2

AQUIFER CHARACTERISTICS OF THE LOWER SILTY SAND ZONE
BASED ON THE ANALYSIS OF REI-3-4 TEST (AUGUST 21-24, 1986)

Observation Well	Method	Selected Pumping Interval	Transmissivity (gpd/ft)	B[(1)] (ft)	Hydraulic Conductivity (cm/sec)	Coefficient of Storage
REI-11	Black and Kipp B = 2.0	100-2200 minutes	965	20	2.28×10^{-3}	6.1×10^{-5}
REI-11	Theis	100-1500 minutes	632	20	1.49×10^{-3}	1.01×10^{-4}
REI-10-1	Black and Kipp B = 0.5	90-2100 minutes	822	25	1.55×10^{-3}	6.05×10^{-5}
REI-10-1	Theis	90-1100 minutes	632	25	1.19×10^{-3}	7.63×10^{-5}
REI-3-4	Jacob Semi-log (Recovery)	70-700 minutes (into recovery)	728	25	1.37×10^{-3}	7.14×10^{-4}

(1) B = Average Aquifer Thickness

rainfalls continued until about 21:00 on August 23. Total rainfall reported in the RI Field notes was 0.05 ft. The response deviation from the extrapolated drawdown in response to pumping predicted by Theis (1935) in all three wells was 0.08 feet (Figures 6-6, 6-7 and 6-8). This is convincing evidence that the loading phenomenon covered a relatively large area as would be expected from a precipitation loading response. The response deviation cannot be attributed to pumping at the REI-3-4 well as there is no relation to distance from the well. The difference between the precipitation estimate and the precipitation loading response measured in the three wells completed in the lower silty sand zone could be the result of precipitation measurement error or the effect of additional loading from surface runoff from upland areas.

6.3 INITIAL TEST AT REI-10 WELL CLUSTER (September 15 to 19)

6.3.1 Procedures

A pressure transducer/data logger system was used to record water levels in the observation wells and clay piezometers during the test. This allowed a detailed record of water level variations to be maintained. According to the work plan and from previous discussions it was agreed that transducer measurements would be verified periodically using standard water level sounders. Unfortunately, during the initial test water levels were checked with with manual well sounders only twice. As discussed later, these checks indicated significant discrepancies between the manual and transducer readings.

The pumping rate during the test was to be maintained within a range of +/- 0.1 gpm. A new digital flow meter was installed in the line and frequent readings were taken and valve adjustments made to maintain the preselected pumping rate of 20 gpm. The 20 gpm rate was selected based on the results of a 1.5 hour test on August 16, 1986.

The test was run for 27.5 hours and was terminated because an anomaly appeared in the response in well RE_10-3 completed in the shallow zone adjacent to well GW-25.

6.3.2 Results and Interpretation of 27.5 Hour Test

Interpretations of response data recorded in observation wells completed in the deep silty sand zone were made using traditional hydrologic methods for nonsteady state conditions. The semi-log analysis technique of Jacob (1940) was first used to interpret the results from the GW-25 observation well. Use of the semi-log method is valid as long as the dimensionless "u" parameter is less than 0.1. The "u" parameter decreases with longer time values and when the radial distance between the observation well and the pumping well decrease. The results, as provided in Figure 6-9, suggest an apparent boundary effect about 400 minutes into the test. Shortly after that it was not possible to maintain the 20 gpm flow rate. Pumping rates for the remainder of the test varied from 12 to 15 gpm. Semi-log analysis of the drawdown results for GW-25 prior to 400 minutes indicates a transmissivity value of 1992 gpd/ft. and a storage coefficient of 0.00015. The corresponding value of the "u" parameter at 50 minutes into the test was .0178.

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Pumping rates were not checked with a bucket and stop watch during this initial 27.5 hour test. However, we believe that the flow meter was working properly during the initial test even though the meter was found to be malfunctioning during the subsequent 7-day pump test. Semi-log analysis of the GW-25 response produced results almost identical to the semi-log analysis of the GW-25 response observed during the 1.5 hour pretest of August 16, 1986, provided in Figure 6-10. Results for this pretest with a measured pumping rate of 8 gpm were: estimated transmissivity value of 2011 gpd/ft., a storage coefficient of 0.00017, and a corresponding "u" value at 40 minutes of 0.0256.

Analyses of the response at observation well GW-25 during the early portions of the test before "boundary effects" appeared provide good estimates for aquifer characteristics in the vicinity of the pumping well. Because GW-25 well response was available during this test, the response at GW-25 will used to obtain aquifer characteristics. Type curve analyses produced results similar to the semi-log analysis. A Theis Curve match of the log-log response between 0.5 and 400 minutes as shown in Figure 6-11 resulted in a transmissivity estimate of 1834 gpd/ft. and a storage coefficient of .00025. The match was not particularly good. A better match resulted using the Type Curves of Black and Kipp (1977) which consider observation well response delay resulting from the effects of well losses and well bore storage. The Black and Kipp type curve with B=2.0 produced the best match with the response provided in Figure 6-11. Corresponding estimates for transmissivity and storage coefficient are 2292 gpd/ft. and 0.00012.

Water level responses of the REI-11, REI-3-4 and REI-12-1 wells completed in the lower zone are shown in Figures 6-12, 6-13 and 6-14. Analysis results for the lower zone wells are provided in Table 6-3. The nonuniform nature of aquifer characteristics is apparent from these results. The results of this pump test as well as the pump test at well REI-3-4 reported in Table 6.2 indicate that transmissivity decreases in the vicinity of the REI-3-4 well. The results suggest that perhaps lower transmissivities exist in the vicinity of the REI-12-1 well. However, because of the large radial distance between the pumped well and well REI-12-1, it is not possible to determine the transmissivity in the vicinity of the REI-12-1 well from this analysis. On the basis of relative well yields, it appears that the transmissivity in the vicinity of well REI-12-1 is lower than around wells REI-10-1 and REI-11 but slightly higher than around well REI-3-4. Consequently, it appears that the "boundary effects" that became apparent after about 400 minutes into the test were the result of nonuniform aquifer characteristics.

The only aquitard response in the first test was an apparent rise in the pressures in the silt piezometer P-10-2 as shown in Figure 6-15. We indicate that the rise is apparent because no manual well sounder measurements were taken to confirm the response. Furthermore, the erratic behavior of the response suggests possible transducer measurement problems. Nevertheless, the initial rise in the water level in P-10-2 at the beginning of the test and corresponding drop upon termination of pumping in the lower zone is consistent with observations in the subsequent retest on Sept 19 and 7 day test starting on October 7. Similar responses observed in certain regions around pumping wells in both stratified formations and fractured aquifers have been referred to in the literature as the "reverse water level

TABLE 6-3

AQUIFER CHARACTERISTICS OF THE LOWER SILTY SAND
REI-10-1 27.5 HOUR TEST (SEPTEMBER 15-16, 1986)

Observation Well	Method	Selected Pumping Interval	Transmissivity (gpd/ft)	B(1) (ft)	Hydraulic Conductivity (cm/sec)	Coefficient Storage
GW-25	Black and Kipp B = 2.0	0.7 -60 minutes	2292	25	4.32×10^{-3}	1.2×10^{-4}
GW-25	Theis	0.7-300 minutes	1833	25	3.46×10^{-3}	2.5×10^{-4}
GW-25	Jacob Semilog	10-200 minutes	1922	25	3.76×10^{-3}	1.5×10^{-4}
REI-11	Theis	10-100 minutes	1637	20	3.86×10^{-3}	1.3×10^{-4}
REI-11	Black and Kipp B = 1.0	10-350 minutes	2464	20	5.81×10^{-3}	4.0×10^{-5}
REI-3-4	Theis	40-750 minutes	824	25	1.55×10^{-3}	6.22×10^{-5}
REI-3-4	Black and Kipp B = 0.5	30-600 minutes	1206	25	2.28×10^{-3}	5.24×10^{-5}
REI-12-1	Theis	150-1000 minutes	458.4	28	7.72×10^{-4}	4.74×10^{-5}
REI-12-1	Black and Kipp	150-900 minutes	739.3	28	1.25×10^{-3}	4.19×10^{-5}

(1) B - Average Aquifer Thickness

fluctuation" or "Noordbergum" effect (Streltsova, 1976). Wolff (1970) attributes the reverse water level response to distortion of the pore space in the aquitard resulting from the shear transfer of radial strains in the aquifer near the pumping well.

During the 27.5 hour test, transducer measurements showed a pressure rise in wells REI-10-2 and REI-10-4 and a pressure drop in well REI-10-3 (Figures 6-16, 6-17 and 6-18). Initially this differential response was thought to be due to leakage through the GW-25 well. Other factors suggest that there was no differential response in the wells in the alluvial aquifer due to pumping the lower zone. First, there was no recovery in the differential response between REI-10-3 and the other two wells once pumping of well REI-10-1 was terminated. Second, manual well sounder data collected on the morning of Sept. 16 and Sept. 17 showed water levels to be nearly identical to the pre-test levels and did not correspond with the levels inferred from transducer measurements (see Figures 6-16, 6-17 and 6-18). Third, insufficient rainfall occurred during the period to produce a water level rise of the magnitude indicated by the transducers in REI-10-2 and REI-10-4. Lagoon levels dropped by 0.01 ft between the start of the test and the afternoon of September 17. Furthermore, had water levels in the alluvial aquifer actually come up on the order of 0.4 to 0.5 feet as indicated by the transducer measurements, a blanket loading response would have been observed in the silt and clay piezometer. Fourth, a retest of REI-10-1 failed to produce a differential response between REI-10-3 and the other two alluvial wells at the REI-10 well cluster. Finally, subsequent comparison of well sounder and transducer measurements has shown that transducer measurements were often unreliable. Consequently, we doubt whether pumping the lower zone induced a response in the alluvial aquifer near GW-25 during the initial 27.5 hour test.

Following retest of well REI-10-1 on September 19, the decision was made to drill out GW-25 to examine the likelihood of limited leakage through the well bore and to eliminate this possible source of leakage. Although AHA was not present during the drilling and plugging of GW-25, it is our understanding that little firm grout was encountered in the annular space. Rather, a viscous jell consisting of primarily of drilling mud was discovered. While this material was unlikely to support a high rate of leakage, it is possible contaminants may have migrated to the lower zone through the annular space via fluid transport under the prevailing strong vertical head gradients.

6.4 SEVEN DAY DRAWDOWN TEST AT THE REI-10 WELL CLUSTER (October 3-17)

6.4.1 Pretest Monitoring (October 3-7)

Well and piezometer water levels, barometric pressure, lagoon levels and precipitation were monitored intensively with transducer measurements recorded every 10 minutes and manual well soundings taken every 2 hours for three days prior to the start of the long-term pump test on REI-10-1. The primary purposes of the pre-test monitoring were:

1) to determine whether that well and piezometer levels were at equilibrium,

2) to evaluate well and piezometer response to barometric pressure fluctuations and other possible external influences so that these influences could be factored into any analysis of response due to pumping, and

3) to determine the reliability of the transducer measurements.

The pre-test monitoring data is shown in Figures 5-2 to 5-4 and 6-19 to 6-22. The upper zone well levels appear to show response to evapotranspiration. Evapotranspiration produces a drawdown in the water table at locations where the water table is close to the surface where plant roots can reach the saturated zone or capillary fringe. These effects are observed in the lower parts of the upper alluvial zone due to the apparent good vertical hydraulic communication within the upper alluvial zone.

There were no significant precipitation events during the pre-test period so the response to these events could not be observed. Response to these events were apparent during the test when several significant precipitation events occurred.

The water levels in the lower silty sand zone wells and middle clayey zone piezometers did not show any significant response to barometric fluctuations during the pretest monitoring period or during any of the testing periods. As discussed previously, the lack of barometric influence in these confined zones indicates that stress imposed by barometric pressure changes is compensated predominantly by pore pressure changes and not by changes in effective stress (intergranular pressures). Significant precipitation events did not occur during the pretest monitoring period so precipitation loading effects were not observed until after the start of the 7-day pump test.

Additional pretest monitoring data are available for the months of August and September. These data are included in Figures 6-23 and 6-24 for selected monitoring wells. Since several different sounders were used, the data must be interpreted with caution. Nevertheless, several conclusions can be reached. First, Piezometer P-10-3 did not reach equilibrium until the middle or latter part of September. Second, water level fluctuations in P-10-2 and P-10-4 appear to track the fluctuations in the alluvial aquifer. Furthermore, the water levels in all the wells and piezometers demonstrated a significant and comparable response to the high precipitation that occurred between September 5 and September 15. These results further support the concept of efficient and sustained pore pressure responses in confined units to loadings imposed by significant precipitation events.

6.4.2 Pump Test Results and Interpretation

The drawdown portion of the test was conducted for just over seven days. About 3 hours into the test it was discovered that the flow meter being used to measure pumping rate was not functioning properly. Bucket and stopwatch check measurements confirmed the problem and for the remainder of the test bucket and stop watch measurements were used to maintain the pumping rate from the REI-10-1 well at 17 gpm +/- 0.5 gpm.

Measurement of precipitation, barometric fluctuations and lagoon levels during the test are shown in Figures 6-25 to 6-27. Water level response in most wells and piezometers were measured using transducers and periodic manual checks were made with standard well sounders. The REI 12-1 well was measured using manual measurements only. The responses of all wells are shown in Figures 6-28 to 6-38. The transducer and manual measurements track reasonably well but there were some significant magnitude differences which appeared in a number of the transducers.

The In Situ test system was struck by lightening prior to the start of the test. The Unit was sent back to the supplier for repair and defective transducers were replaced. For most of the transducers, the discrepancy between sounder measurements appeared to increase as levels changed from the initial levels. As notes previously this suggests these transducers may have been off calibration. For consistency and overall reliability, manual measurements were mostly used for the analysis.

Response in the Lower Zone.

The response of the lower zone wells have been plotted on log-log paper in Figures 6-35 to 6-38. The response of the GW-25 well to earlier pump tests on the REI-10-1 well indicated that the lower zone is not homogeneous and that a zone of lower permeability exists at some distance from the REI-10 site. The low yield of the REI 3-4 well suggests a lower permeability for the zone in the vicinity of this well. Since the GW-25 well was plugged prior to the 7-day test on REI-10-1, the closest observation well in the pumped zone was the REI-11 well some 400 feet away. The lack of a close observation well makes the observation of boundary effects difficult. To be conservative, the early time drawdown data, which presumably would be less affected by nonhomogeneous conditions were favored in match curve analysis of the responses. A summary of results and analysis is given in Table 6-4 . The results correspond closely with the estimates developed from the 27.5 hour test reported in Table 6-3.

The water levels in wells completed in the deep silty sand units appear to respond not only to pumping of the REI-10-1 well but also to stresses imposed by blanket loads associated with precipitation events. The response to the major precipitation event that occurred about 7000 minutes into the test is apparent in the log-log drawdown plots of lower zone wells provided in Figures 6-35 to 6-38. The response to this precipitation event in the REI-11 well has been illustrated more obviously the arithmetic response plot presented in Figure 6-39.

Response in the Middle Clayey Zone

The middle zone piezometer water levels respond to as many as three superimposed stresses during the pumping test. The P-10-2 piezometer showed responses to all three stresses.

The first type of response is a very rapid increase in pore-pressure after the pump is turned on. The effect has been documented in a number of other studies and in the earlier tests at this site. Wolff 1970) has attributed this reverse water level response to stress imposed on adjacent confining units as a result of lateral movement of the pumped zone in the vicinity of the pumped well. This response was observed only in piezometer P-10-2. It

TABLE 6-4

AQUIFER CHARACTERISTICS OF THE LOWER SILTY SAND
REI-10-1 7 DAY TEST (OCTOBER 7-14, 1986)

Observation Well	Method	Selected Pumping Interval	Transmissivity (gpd/ft)	B(1) (ft)	Hydraulic Conductivity (cm/sec)	Coefficient Storage
REI-11	Theis	10-200 minutes	1372	20	3.24×10^{-3}	1.2×10^{-4}
REI-11	Black and Kipp B = 1.0	10-200 minutes	2214	20	5.22×10^{-3}	3.3×10^{-5}
REI-3-4	Theis	50-600 minutes	847	25	1.60×10^{-3}	5.9×10^{-5}
REI-3-4	Black and Kipp B = 0.5	50-600 minutes	1372	25	2.59×10^{-3}	3.4×10^{-5}
REI-12-1	Theis	150-1000 minutes	424	28	7.13×10^{-4}	4.3×10^{-5}
REI-12-1	Black and Kipp	150-900 minutes	749	28	1.26×10^{-3}	1.3×10^{-5}

(1) B = Average Aquifer Thickness

is uncertain whether this response has any relationship to aquitard permeabilities or storage characteristics.

In this analysis, this "reverse water level response" which occurred at the beginning of the test and ceased when pumping stopped was removed from the total response in P-10-2 to determine the other two response patterns. It was also necessary to correct for a systematic data error that occurred as a result of changing the well sounder after 6100 minutes into the test.

The second type of response is an increase in pore pressure resulting from increases in total stress associated with blanket loadings from large precipitation events. This type of response was observed in all the confined units on site including the deep wells. The response was observed for all precipitation events greater than about 0.05 feet.

The response in P-10-2 to a rainfall starting about 1600 minutes into the test was almost identical in magnitude and timing as the rise in water levels recorded on the lagoon staff gage. The lagoon did not appear to have any surface water inflows or outflows and is deemed to be a more accurately reflect precipitation magnitudes than the "test tube" rain gauge that was monitored on site.

The response in P-10-2 to a larger precipitation event starting about 7100 minutes into the test was nearly twice the magnitude of the rise in water levels recorded on the lagoon staff gage. It is presumed that the larger response occurred as a result of additional loadings associated with surface runoff to the sloughs in the vicinity of the test site.

The third type of response observed in P-10-2 is a decrease in pore pressure resulting from pumping the lower aquifer. This response was observed in the silt piezometer after about 7000 minutes into the test and was not observed in the clay piezometers.

After isolating the response to pumping of the lower aquifer it is possible to analyze this response to determine hydrologic characteristics of the interval between the top of the pumped zone and the silt unit within the middle clayey zone. The analysis technique deemed most appropriate to analyze this type of response is the ratio method described by Neuman and Witherspoon (1972). Use of the method in this case is based on the assumption that the response of the silt unit to pumping the underlying deep silty sand aquifer may be treated in isolation of the "reverse water level fluctuation" due to pumping and the pore pressure increase resulting from blanket precipitation loads. In effect this invokes the principle of superposition described in most basic texts on groundwater hydrology.

The method of Neuman and Witherspoon (1972) assumes that the drawdown response in the pumped aquifer follows a Theis response. This is a reasonable approximation for the REI-10-1 test as illustrated by the comparison of the observed response at REI-11 with a matched Theis curve in Figure 6-35. The method provides an estimate of the vertical diffusivity of the aquitard from the ratio (s'/s) of drawdown response in the aquitard and the pumped aquifer at the same radial distance from the pumping well at time t after pumping starts. The calculations involved in applying the method are provided in Appendix 4. The calculations performed at three separate times during the response period indicate a diffusivity for the aquitard of about 0.2 cm^2/sec.

The diffusivity,d, is defined as the ratio of the hydraulic conductivity to the specific storage:

$$d = K/Ss \qquad (5\text{-}5)$$

The vertical hydraulic conductivity of the aquitard , K_v, can therefore be estimated provided the specific storage coefficient (Ss) is known.

Using the specific storage values calculated from consolidation tests of the clay zones from Table 5-1 as reasonable estimates for the storage characteristics of the middle clayey unit between the silt piezometer and the silty sand aquifer., the average vertical hydraulic conductivity for this unit is calculated at about 7×10^{-7} cm/sec. This value is considered to be conservatively high as the average specific storage of the tested interval is likely to be lower than that calculated for the clay unit.

The clay piezometers do not appear to show a drawdown response due to pumping the underlying aquifer. This is not surprising, since the underlying silt zone did not respond until about 7000 minutes into the test.

The response in both the clay and silt piezometers to the blanket precipitation loads may be analyzed by slug test techniques to estimate horizontal permeabilities in the clay and silt units. Even though the piezometer installations in the middle zone used small diameter pipe to minimize these well bore storage effects, the permeability of the clays and silt are sufficiently low that there is a lag in the piezometer response to the rapid pore pressure increase following blanket loads from intense precipitation events. The slug test analysis assumes that the pore pressure response is instantaneous when in fact the response changes over the duration of the storm. This assumption will have least significance if results can be obtained from short, high intensity precipitation events. Otherwise interpretation of results from the later part of the test should be used to minimize the effects of a gradual pore pressure response.

The methods described by Cooper and Papadopulos (1967, 1973) and Hvorslev (1951) were used to analyze data from the silt piezometer, P-10-2, for the precipitation event starting at 1650 minutes into the test. The total pore pressure response, Ho, of 0.12 ft was determined from both the lagoon water level change and the post event equilibrium level in P-10-2. The hydraulic conductivity estimates are provided in Table 6-5. Supporting calculations are provided in Appendix 4.

Only the latter part of the response data provided in Figure 6-40 fit the Cooper-Papadopulos type curves. The Hvorslev plot in Figure 6-41 appears to fit the data slightly better. The hydraulic conductivity estimates from the two methods agree quite closely and compare quite favorably with the hydraulic conductivity range for silt and loess provided in Freeze and Cherry (1979).

The same analysis techniques were used to analyze the data from the clay piezometer P-10-4 for the precipitation event starting 7100 minutes into the

TABLE 6-5
HYDRAULIC CONDUCTIVITY ESTIMATES IN MIDDLE CLAYEY ZONE
DERIVED FROM PRECIPITATION LOADING RESPONSE

Observation Well	Method	Selected Interval	Assumed Coef. of Storage	Hydraulic Conductivity (cm/sec)
P-10-2	Hvorslev	0-820 minutes	-------	3.08×10^{-6}
P-10-2	Cooper and Papadopoulos	470-820 minutes	5×10^{-4}	2.22×10^{-6}
P-10-2	Cooper and Papadopoulos	470-820 minutes	5×10^{-6}	3.77×10^{-6}
P-10-4	Hvorslev	250-1800 minutes	-------	1.46×10^{-7}

test. The clay piezometers never do reach equilibrium, so the response measured in the silt piezometer, P-10-2, was used to determine Ho, the pore pressure increase in the clay. The Cooper-Papadopulos type curves did not fit the response. The Hvorslev plot in Figure 6-42 fit the P-10-4 response results somewhat better. The results provided in Table 6-5 indicate horizontal hydraulic conductivities in the clay of about 10^{-7} cm/sec. This is slightly higher than the estimates derived for the clay from the slug test analysis of P-10-4 reported in Section 6.6. The slug test results reported in Section 6.6 are considered to be more reliable because the were developed from controlled test conditions where the slug is measured and applied almost instantaneously.

Response in the Upper Alluvial Zone

The water level fluctuation in the upper alluvial zone during the test is illustrated by the three alluvial wells REI 10-2, 10-3 and 10-4 (Figures 5.2, 5.3 and 5.4). The transducer and manual measurements show the same general form although there are some significant discrepancies, particularly during the first 500 minutes of the test when all three alluvial well transducers showed a rise in water level which was not confirmed by several manual measurements. The manually measured water level fluctuations show very good agreement between all three wells while the transducer measurements are more erratic.

It is believed that the transducer measurements may be influenced by calibration drift or some other problem associated with the lightning damage or method of installation. The transducers in the alluvial wells were installed in special tubes to avoid direct contact with contaminated water in the aquifer. It is possible that this arrangement may have also influenced readings as the transducers in the other monitoring wells appeared to correspond more closely with manual readings. Due to the apparent problems with the transducer measurements, the manual measurements were primarily used in evaluation of upper alluvial zone responses.

The upper alluvial zone responded primarily to precipitation and evapotranspiration influences during the test. No response to pumping of the lower zone was apparent. The precipitation response is most evident following the major event starting about 7000 minutes into the test. About 0.22 feet of precipitation fell during a 12 hour period and is reflected in a water level rise in the upper alluvial zone of about 0.5 feet. A second event occurred about 8600 minutes into the test with 0.08 feet of precipitation falling and a resulting water level rise of about 0.2 feet in the upper alluvial zone. The rise in alluvial zone levels is about 2.5 times the precipitation due to the fact that recharge to the zone only fills the intergranular voids which typically form about 30 percent of the total volume in an unconsolidated granular aquifer.

The upper alluvial zone response to evapotranspiration is seen by water level drops of a few hundreds of a foot during the afternoons. The response is superimposed on the response to precipitation events described above. Evapotranspiration withdraws water from the surface of the alluvial zone, but, due to the good vertical hydrologic communication, these effects are seen in the basal sections of the upper alluvial zone monitored by the REI-10-2, 10-3 and 10-4 wells.

6.5 TESTS AT THE REI-12 WELL CLUSTER

During the site visit on July 8, 1986, it was agreed that one well (REI-12-2) would be completed in the alluvium and one well (REI-12-1) would be completed in the deep silty sand unit at a location north of the REI-10 site and north of State Highway 90. The REI-12 site was selected to better define the potentiometric gradient within the lower zone. The alluvial well, REI-12-2, was included to allow for a determination the degree of communication through the confining clay unit during pump testing of well REI-12-1.

The pump testing planned for the REI-12 well cluster was dropped because of schedule delays in other portions of the 1986 field program. Nevertheless, a short term 220 minute test was run on October 2, 1986 in order to determine whether well REI-12-1 might be leaking and thereby providing a conduit for communication between the lower zone and the alluvium. Possible leakage was suspected because of the relatively high pH in water samples taken during the well and an apparent drop in the water level in well REI-12-2 as indicated by a manual water level reading taken about the same time well REI-12-1 was being developed.

The short term test was conducted with an initial flow rate of 4 gpm. This flow could not be sustained after about 30 minutes so the rate was reduced to 3 to 3.5 gpm. After about 100 minutes the pump was lowered into the screened interval and the pumping rate increased to 4 gpm. The generator stopped about 145 minutes into the test. The generator and pump were restarted after about 10 minutes and pumping was continued for another 65 minutes at 4.25 to 4.5 gpm. During the entire test, water levels in the alluvial well REI-12-2 continued to rise at a very slow rate. During the test water levels in REI-12-2 came up about 0.035 ft. while drawdowns in REI-12-1 reached 55.4 ft.

It was concluded that there was no apparent hydraulic communication associated with the REI-12-1 well completion. On the basis of well yields, the aquifer transmissivity in the vicinity of the 12-1 well is lower than at the REI-10-1 location but not as low as at the REI-3-4 location. No attempt was made to estimate transmissivities from these data because of the variable pumping rate and the effects of well bore storage during this relatively short term test.

6.6 CLAY PIEZOMETER RESPONSE TESTS

6.6.1 Procedures

AHA recommended performing single well response tests on the clay piezometers REI-P-10-3 and REI-P-10-4 by adding a known volume of water to raise the initial water levels in each piezometer about 15 to 16 feet. The disadvantage of this approach is that the water cannot be added instantaneously as is assumed by the methods used to analyze response. Fortunately, response tests in low permeability units may involve water level recovery of several weeks so water added over a 10 to 15 minute period represents nearly an instantaneous increase for the time scale of interest.

It was agreed that the transducers would remain in place from the previous test and that the In Situ Hermit data logger would be programmed to record transducer measurements from the two piezometers on a log scale. The starting time for recording would begin immediately before adding the known slug of water so that a good record is developed for when all the water has migrated down the well bore. Manual measurements taken with the same well sounder every few days should provide adequate checks. If transducer measurements and manual measurements show differences of more than 0.1 ft. then we would consider more frequent manual measurements.

REI/ERT agreed to visit the site every two to three days to see that the Hermit is operating properly and to perform manual checks with the well sounder. AHA recommended that the measurements should be taken for thirty days or until water levels are at least within one foot of the equilibrium level.

6.6.2 Results and Interpretation

The slug test response monitoring was conducted over a 30 day period. During this time Piezometer P-10-3 recovered about 35% and piezometer P-10-4 recovered about 28%. Semi-log plots were developed for analysis using the method of Cooper, Bredehoeft and Papadopulos (1967). These plots are provided in Figures 6-43 and 6-44. Storage coefficient values from the laboratory consolidation tests were used to select an appropriate type curve from Cooper et al (1967) to estimate hydraulic conductivity values from the slug test response in the clay piezometers. Semi-log plots were also developed for analysis using the method of Hvorslev (1951). These plots are provided in Figures 6-45 and 6-46. Calculations of hydraulic conductivity estimates using the two slug test analysis techniques are provided in Appendix 5.

The hydraulic conductivity estimates are provided in Table 6-6. The substantial range in the estimates for piezometer P-10-3 are the result of anomalous behavior in the response during the first 2000 minutes of the test. Estimates derived from the early portion of the test are nearly two orders of magnitude higher than estimates derived from the rest of the response data. The estimates derived from the response beyond the first 2000 minutes is thought to be more reliable because of the much longer response time and the confirmation of transducer data with well sounder measurements. The anomalous response in the early portions of the test could be related to completion problems at this well as discussed in Appendix 2 or it could be the result of anomalous transducer readings.

The hydraulic conductivity estimates derived from piezometer P-10-4 are deemed to be more reliable estimates for the clay in the vicinity of the piezometers. The transducer measurements track the manual well sounding measurements reasonably well. Both method have some limitations when applied to the clay piezometers. The method of Cooper et al (1967) assumes that the piezometers are completed in a unit bounded above and below by impermeable boundaries. The method of Hvorslev (1951) assumes that the piezometers are completed within a uniform porous medium. This assumption corresponds more closely to a piezometer completed within the clay. On the other hand, the Hvorslev method does not take into account the storage

TABLE 6-6
HYDRAULIC CONDUCTIVITY ESTIMATES FOR THE MIDDLE CLAYEY ZONE
DERIVED FROM SLUG TEST RESPONSE DATA

Observation Well	Method	Selected Interval	Assumed Alpha Value (approx. 7x coef of storage)	Hydraulic Conductivity (cm/sec)
P-10-3	Hvorslev	0-2000 minutes	-------	2.41×10^{-7}
P-10-3	Hvorslev	4000-40000 minutes	-------	8.92×10^{-9}
P-10-3	Cooper and Papadopoulos	1-1000 minutes	10^{-3}	1.09×10^{-6}
P-10-3	Cooper and Papadopoulos	3000-30000 minutes	10^{-4}	3.07×10^{-8}
P-10-4	Hvorslev	1-20000 minutes	-------	1.99×10^{-8}
P-10-4	Hvorslev	1-43000 minutes	-------	1.38×10^{-8}
P-10-4	Cooper and Papadopoulos	20-20000 minutes	10^{-4}	8.82×10^{-8}

characteristics of the unit. The two methods do provide reasonable bounds for the estimate of vertical hydraulic conductivity of the clay.

Well damage during drilling could affect the reliability of hydraulic conductivity estimates derived from slug tests. During the completion of these piezometers, drilling muds were washed out of the hole after setting the outer casing. The piezometer completion interval was drilled out using water. Any skin effects due to smearing by the drill bit are thought to be of minimal thickness. Faust and Mercer (1984) demonstrate that the effect on the hydraulic conductivity is relatively minor provided the zone affected by smearing is small perhaps on the order of 0.1 cm. Consequently it is believed that any well damage effects should not result in substantial differences between the estimates developed from the P-10-4 response and the actual hydraulic conductivity of the clay.

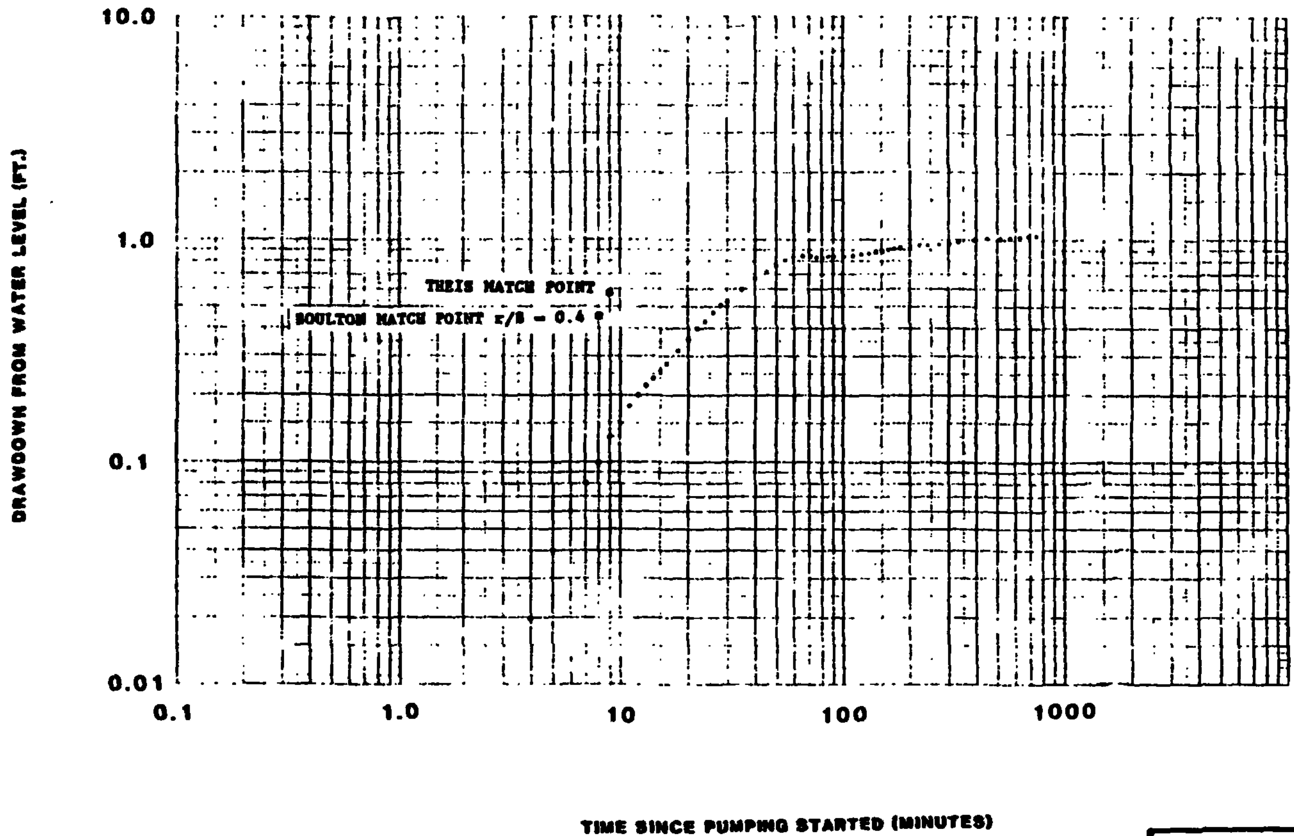

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FIGURE 6-1
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 3-5 PUMPED WELL: REI 3-3
DATE(S): 8/11/86 to 8/12/86 COMMENTS:

PROJECT No. FK86-006	DATE 8-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.

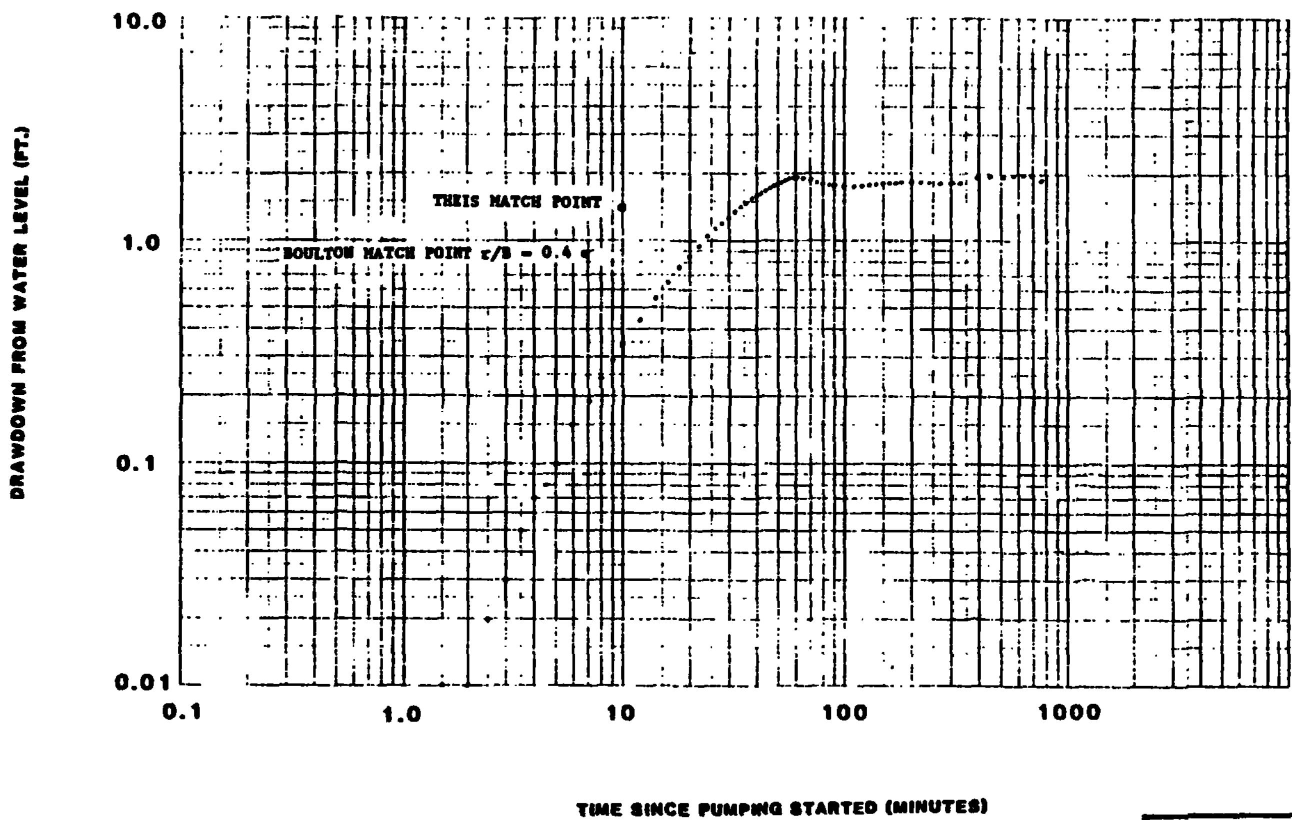

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FIGURE [illegible]
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI P-3-3 PUMPED WELL: REI 3-3
DATE(S): 8/11/86 to 8/12/86 COMMENTS:

PROJECT No. FRTL-006	DATE 11-26-86	REVISION 1

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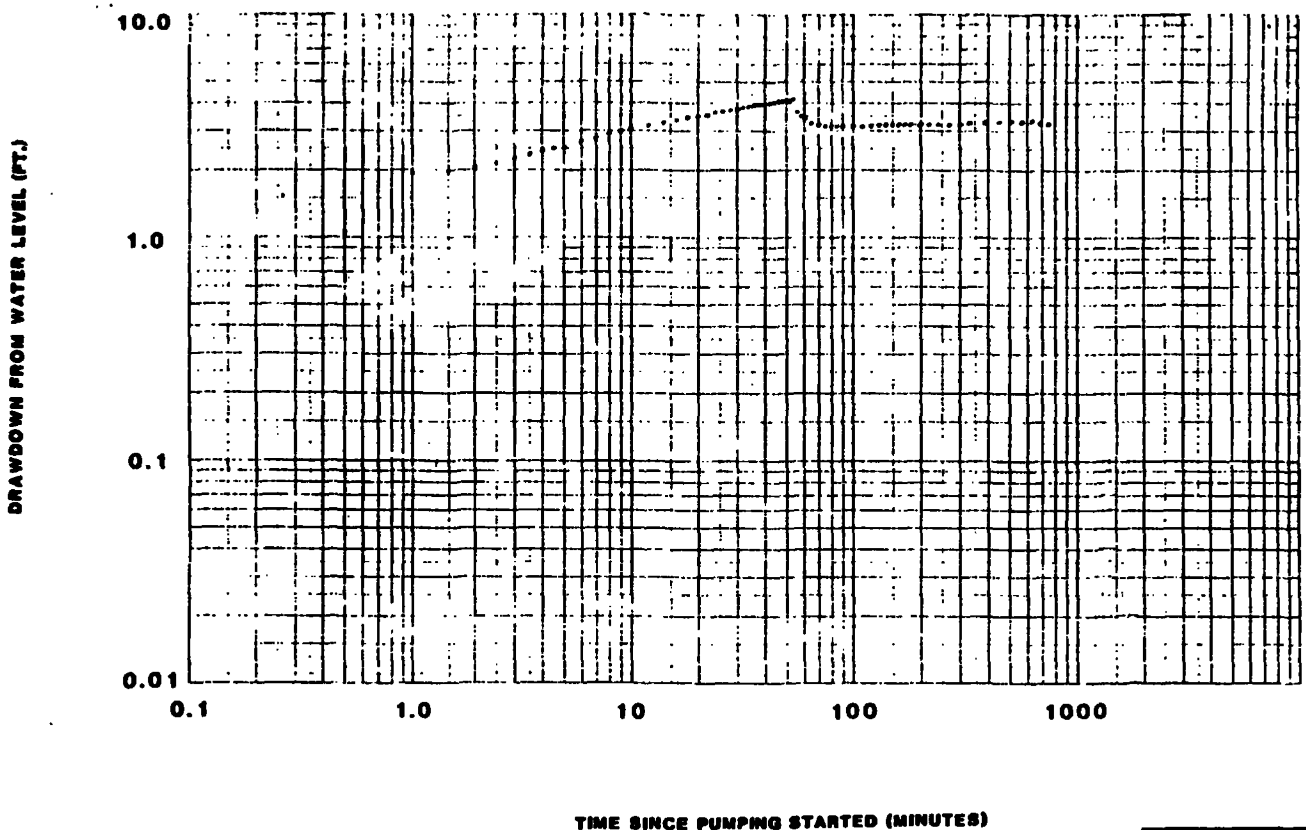

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FIGURE 6-3
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 3-3 PUMPED WELL: REI 3-3
DATE(S): 8/11/86 to 8/12/86 COMMENTS:

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

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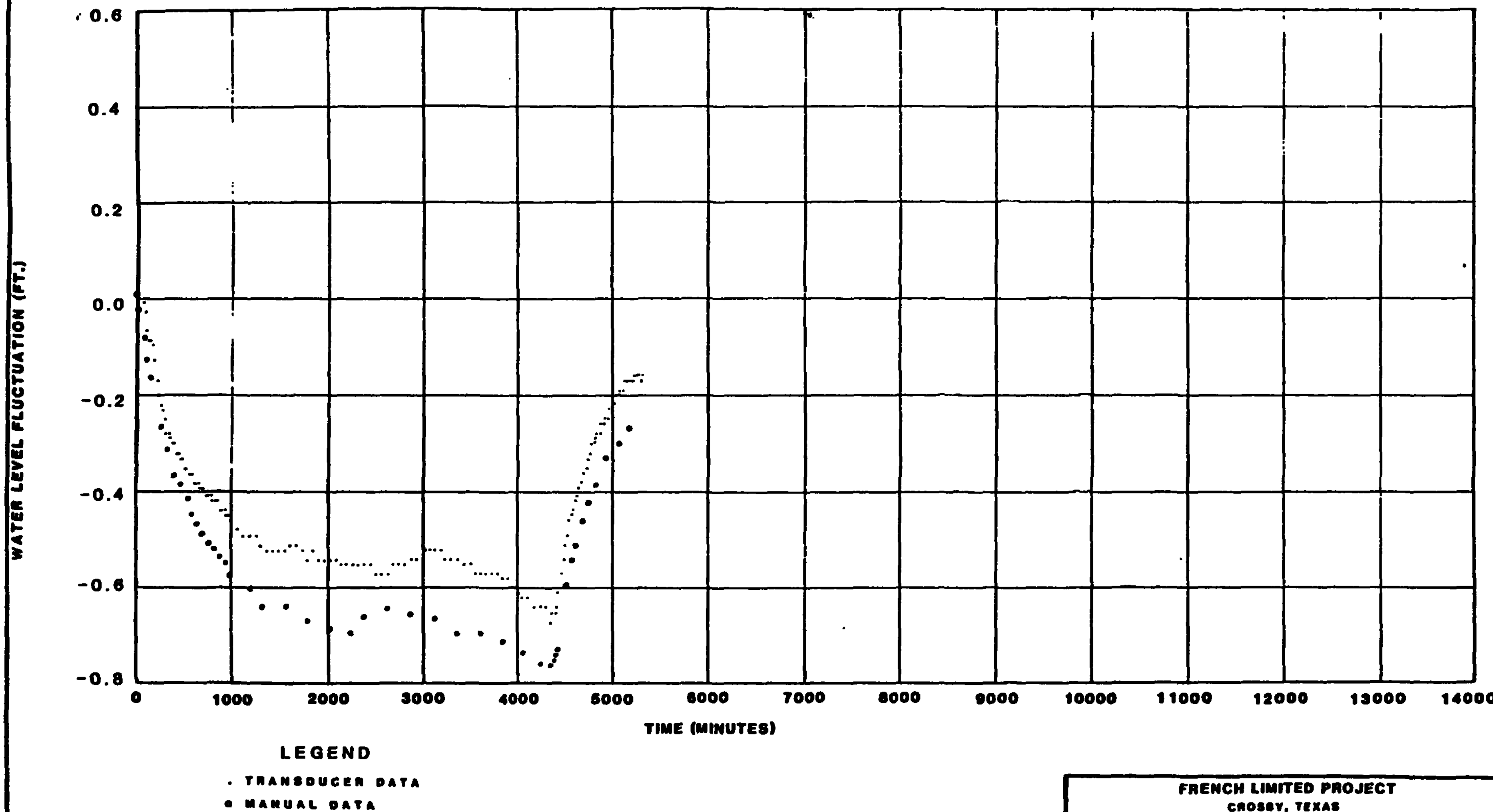

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FIGURE 6-4
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 11 PUMPED WELL: REI 3-4
DATE(S): 8/21/89 to 8/25/89 COMMENTS:

PROJECT No. PR96-006	DATE 11-26-96	REVISION 1

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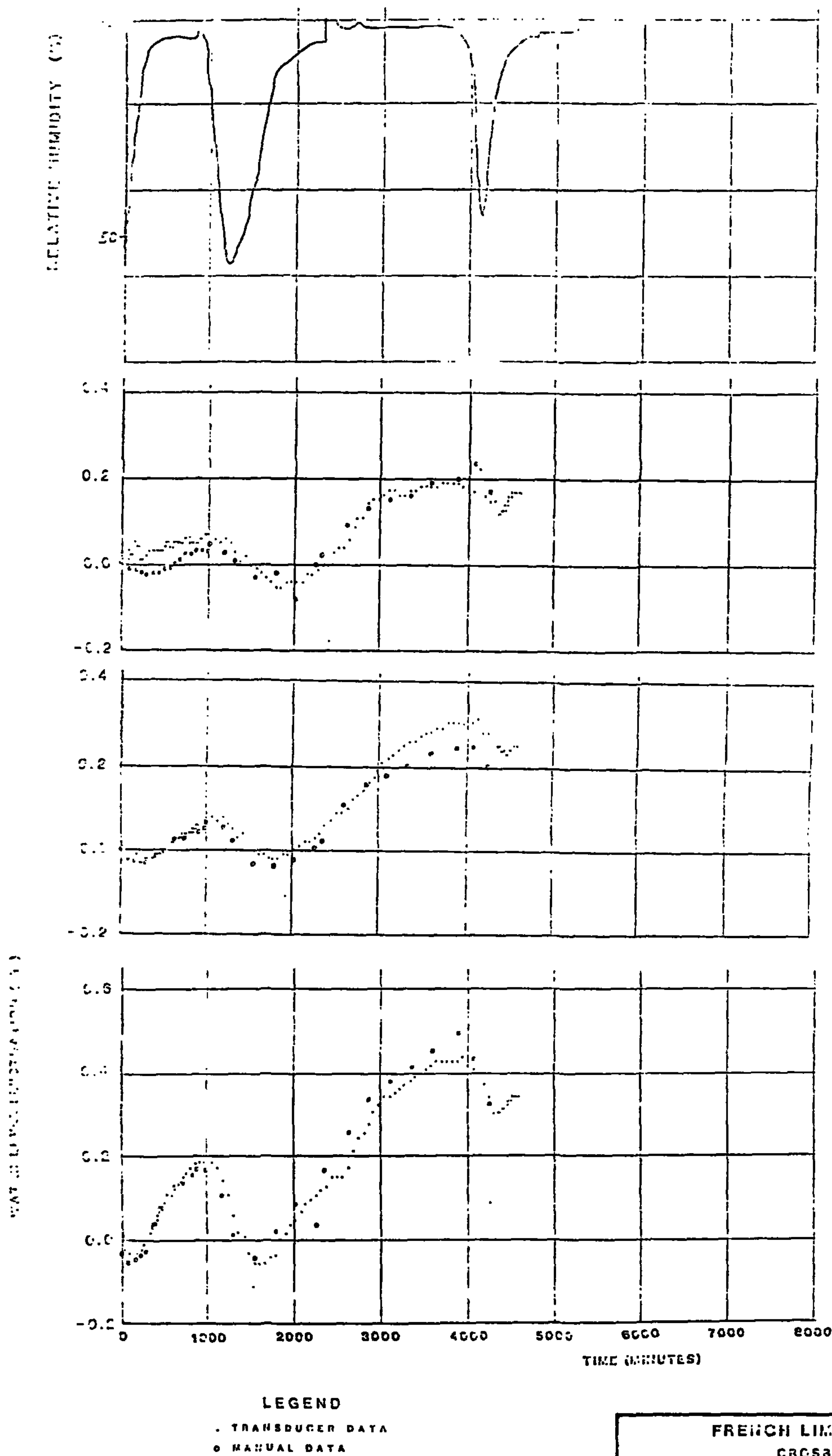

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FIGURE 6-5

RESPONSE OF UPPER ALLUVIAL ZONE WELLS DURING PUMP TEST OF REI-3-4 WELL

PROJECT No. PRP6-006	DATE 11/25/8	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.

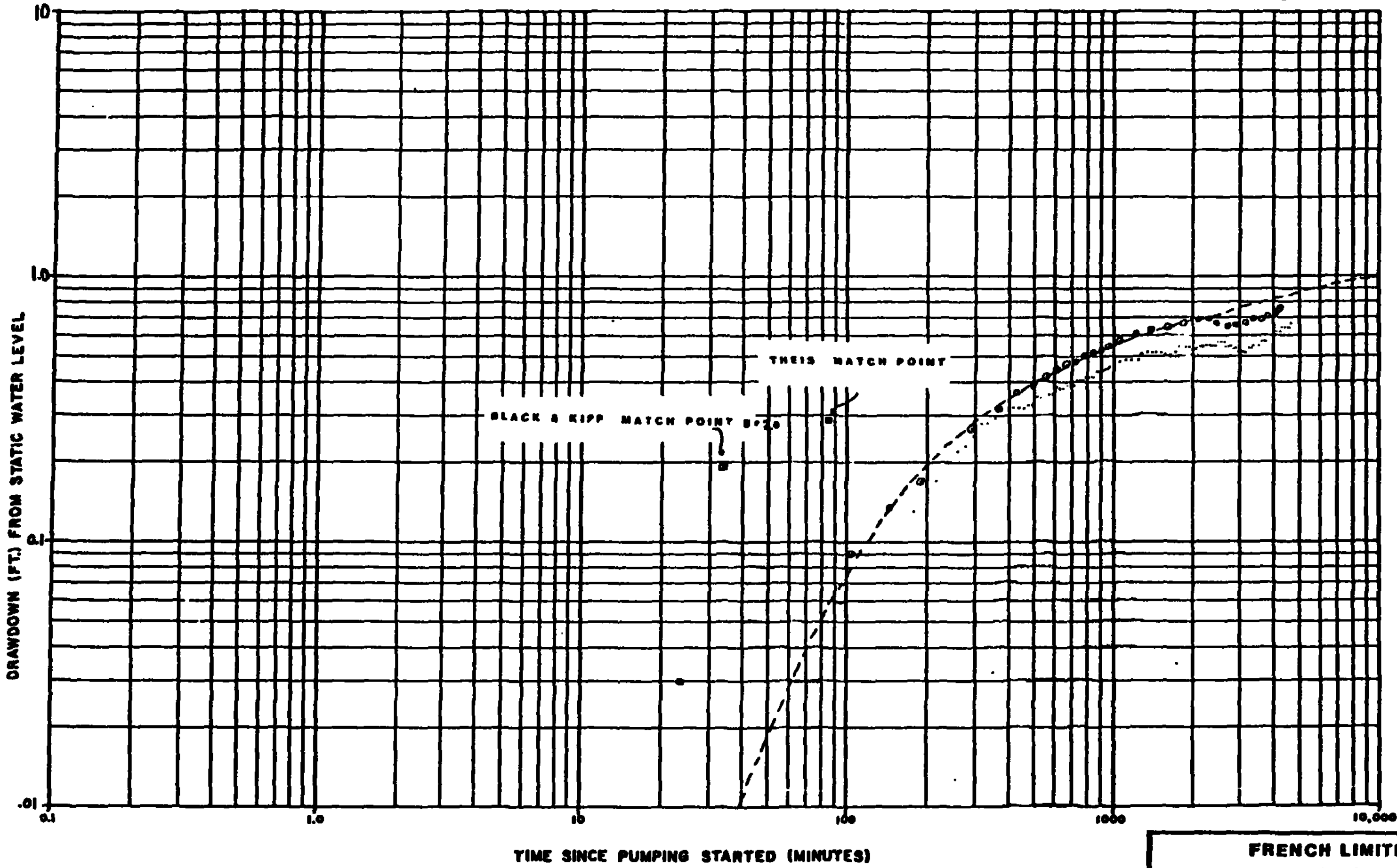

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FIGURE 6-6

WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI-3-4
OBSERVATION WELL: REI-11
DATE(S): 8/21/86 to 8/24/86

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

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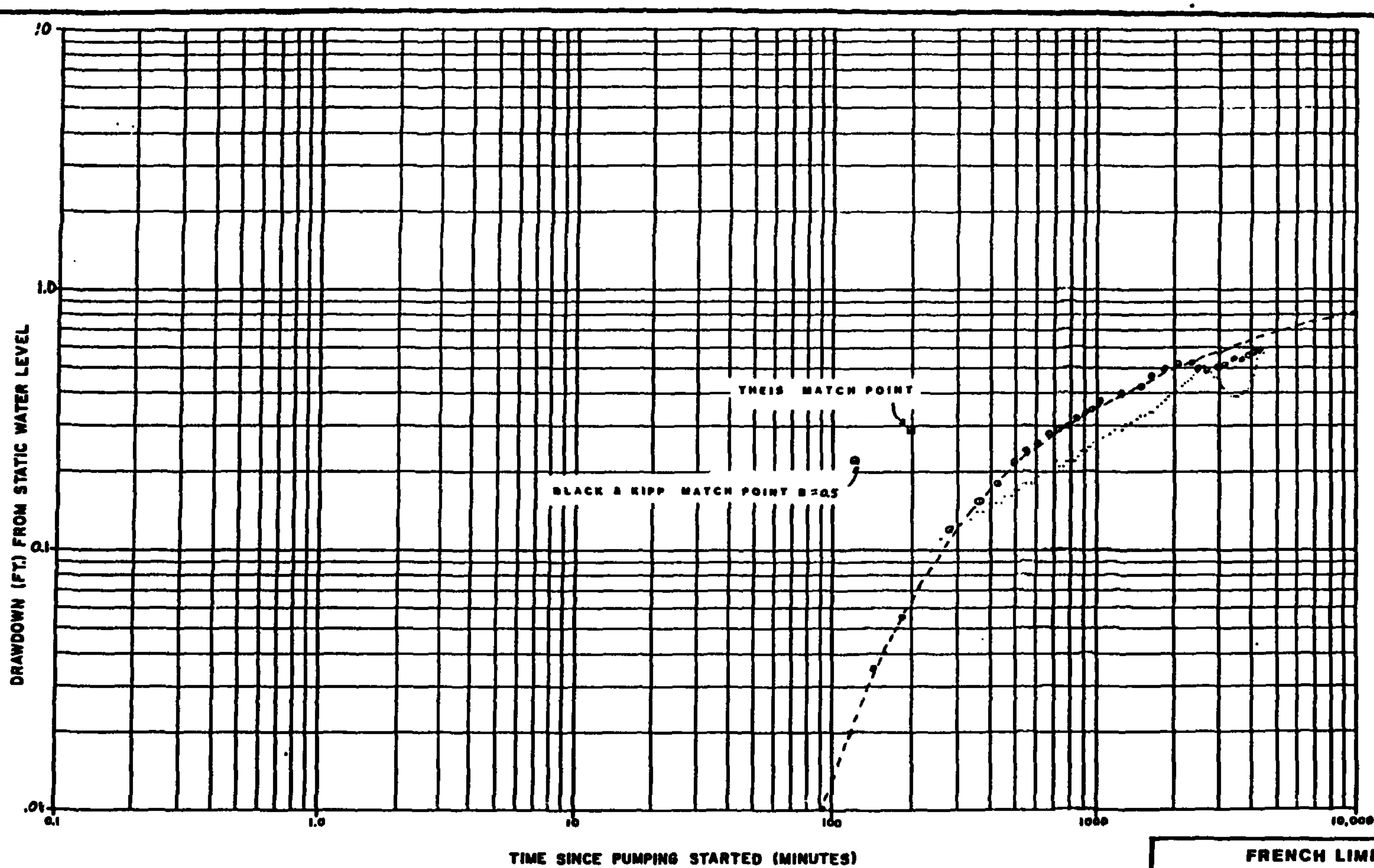

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FIGURE 6-7

WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI-3-4
OBSERVATION WELL: REI-10-1
DATE(S): 9/21/86 to 9/24/86

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

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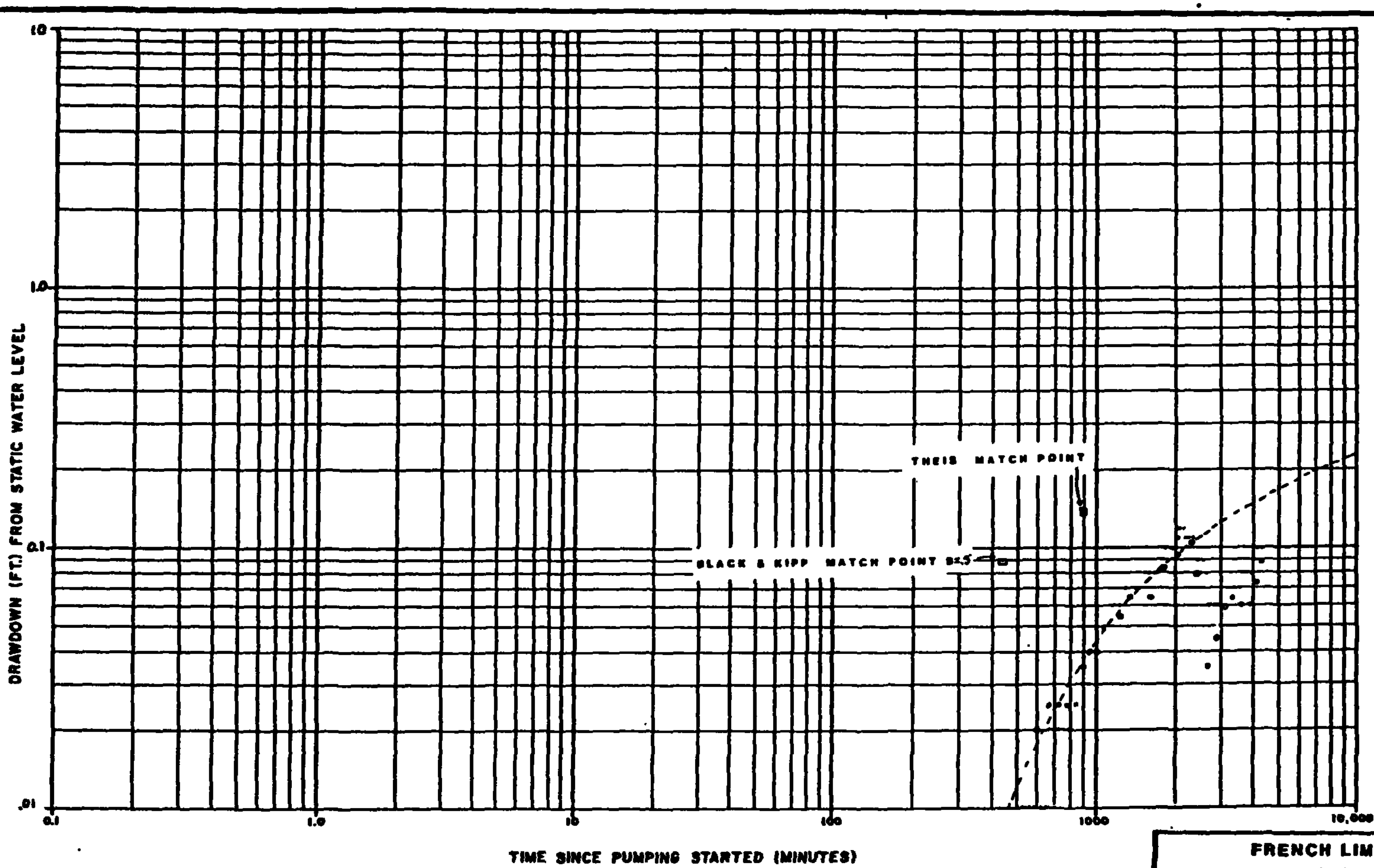

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FIGURE 6-8

WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI-3-4
OBSERVATION WELL: REI-7
DATE(S): 8/21/86 to 8/24/86

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

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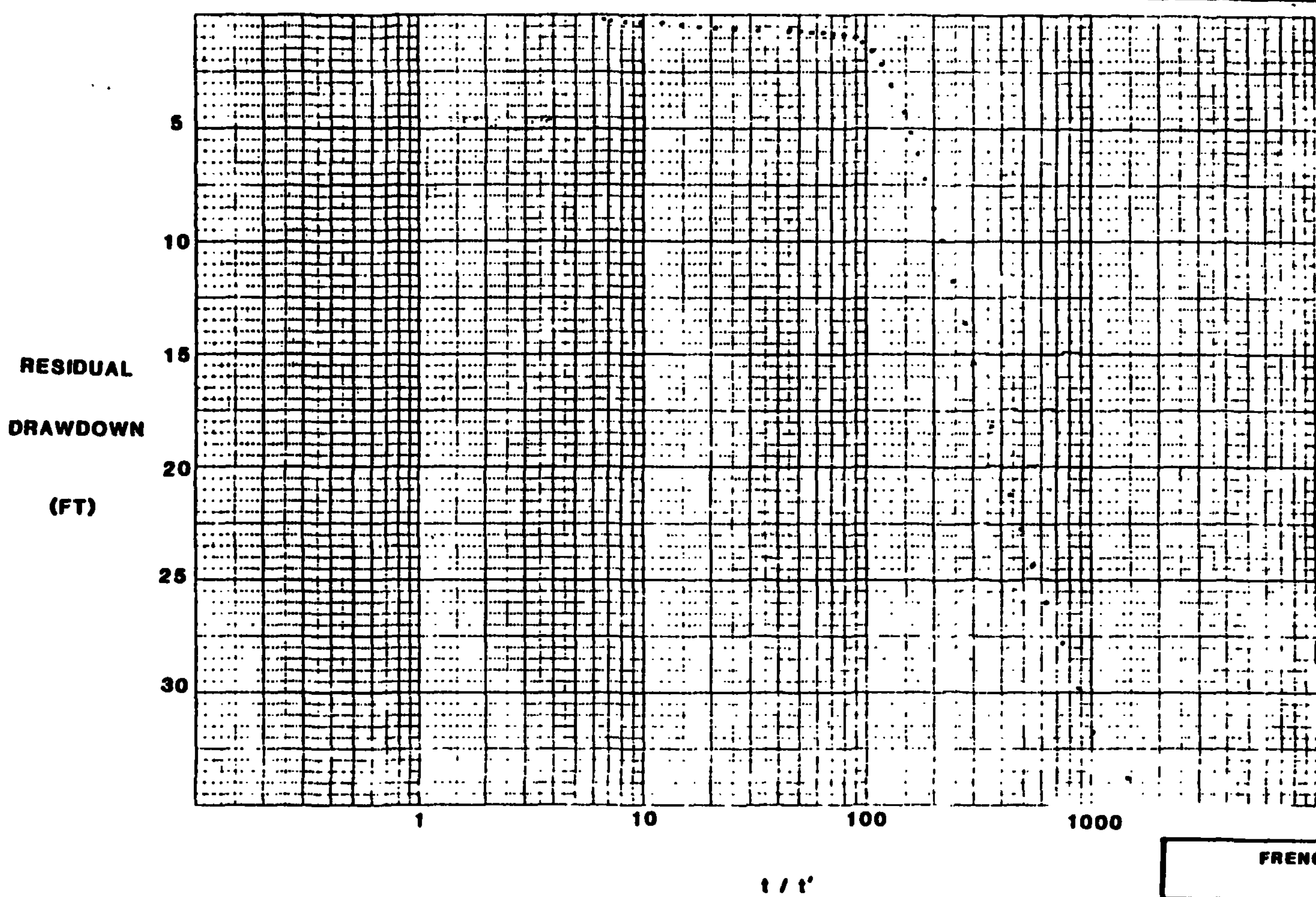

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FIGURE 6-8a

RECOVERY RESPONSE PLOT

PUMPED WELL: REI-3-4
OBSERVATION WELL: REI-3-4
DATE(S): 8/24 to 8/26

PROJECT No.	DATE	REVISION

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.

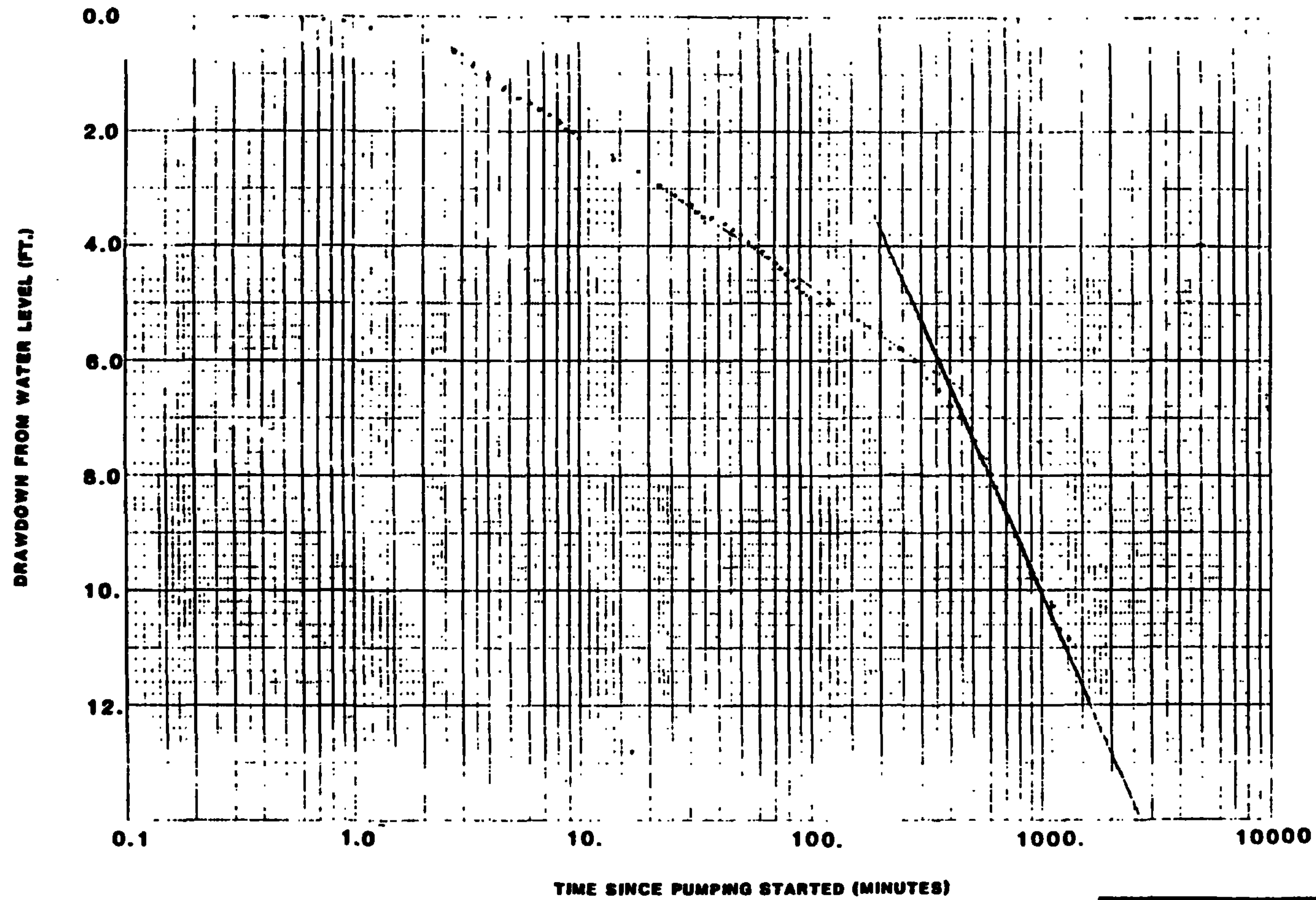

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FIGURE 6-9
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: GW 25 PUMPED WELL: REI 10-1
DATE(S): 9/15/86 to 9/19/86 COMMENTS:

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.

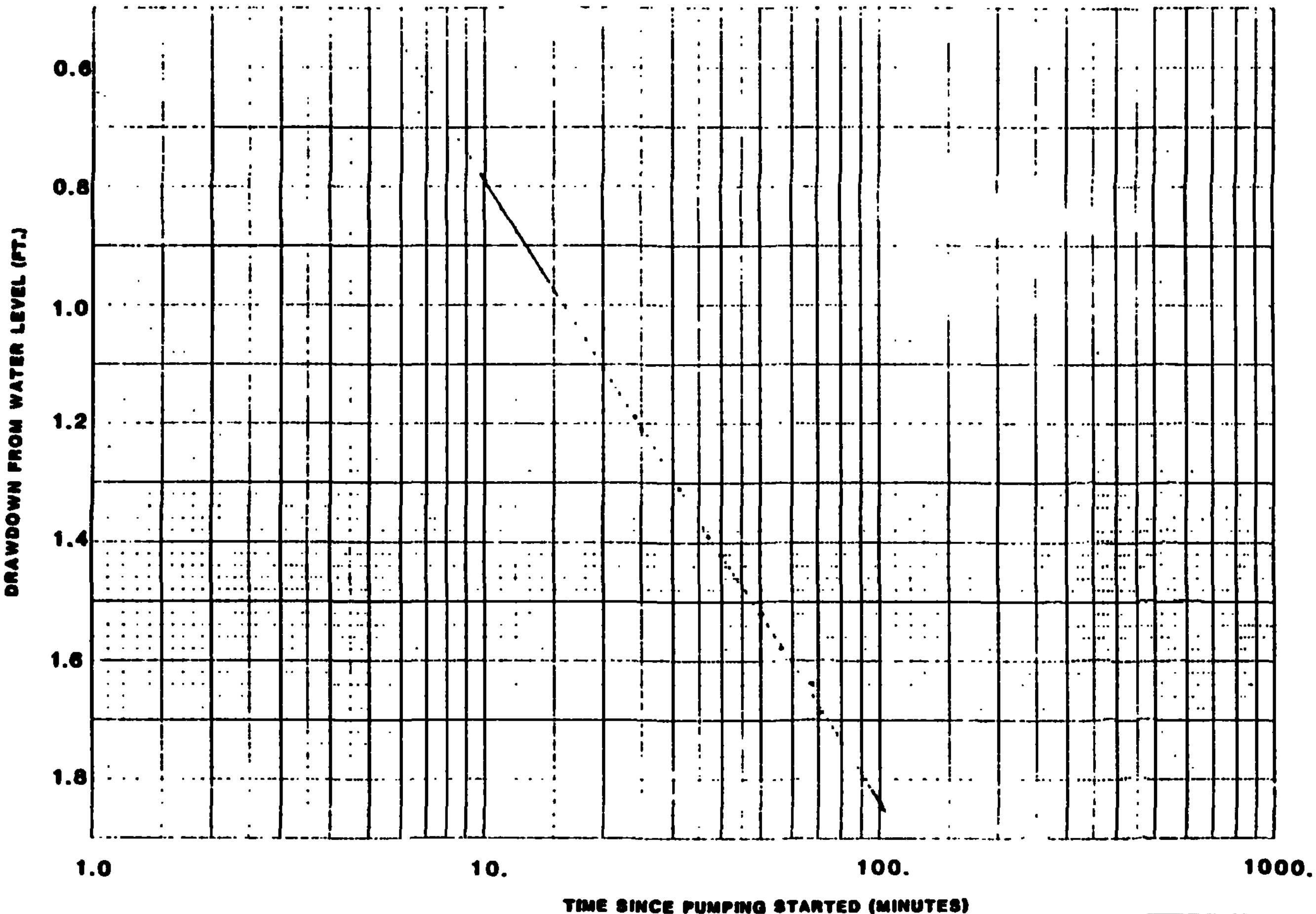

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FIGURE 6-10

WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: GW 25 PUMPED WELL: REI 10-1

DATE(S): 8/16/86 COMMENTS:

PROJECT No. PRP6-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.

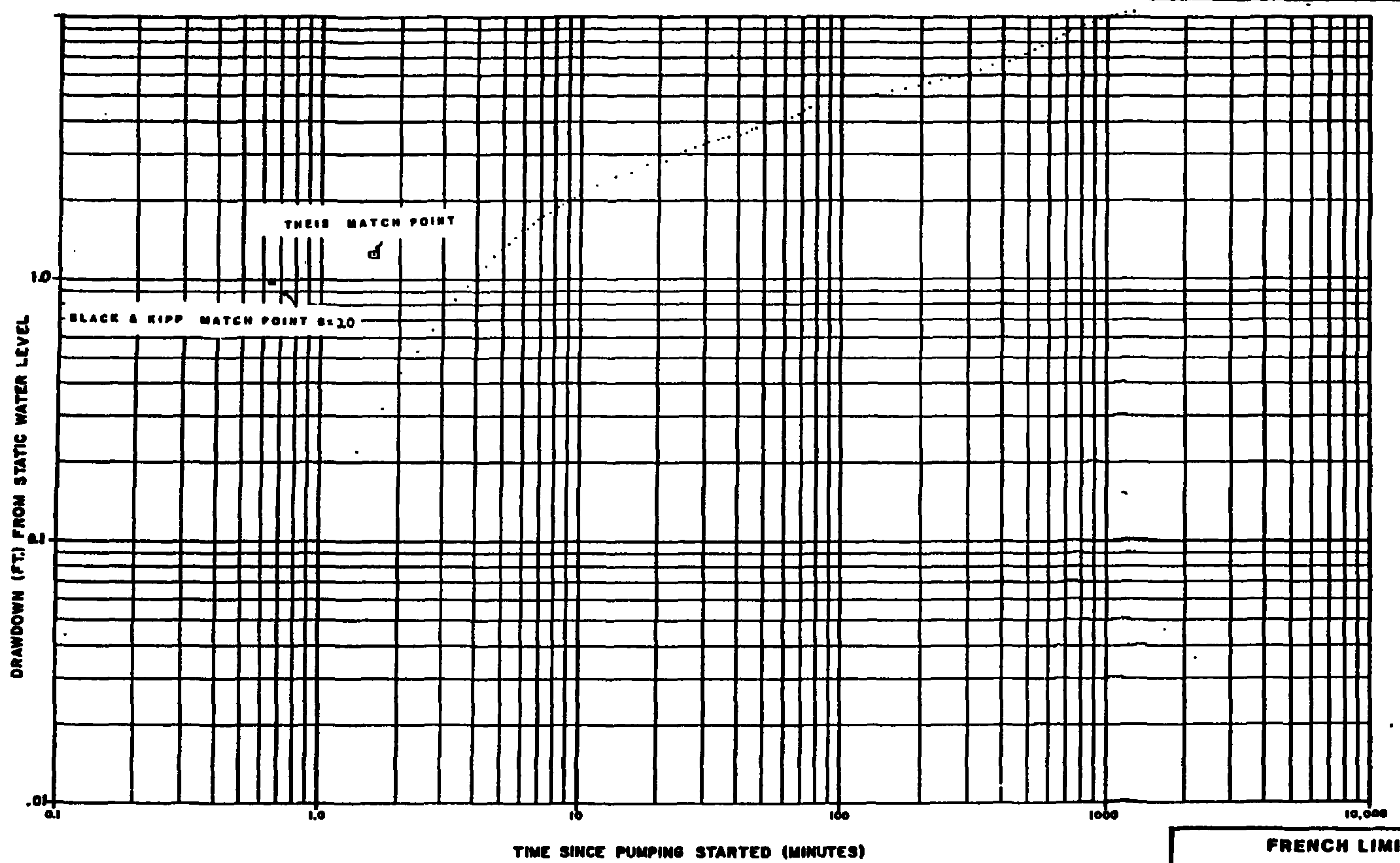

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FIGURE 6-11
WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI 10-1
OBSERVATION WELL: GW 26
DATE(S): 9/16/86 to 9/18/86

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.

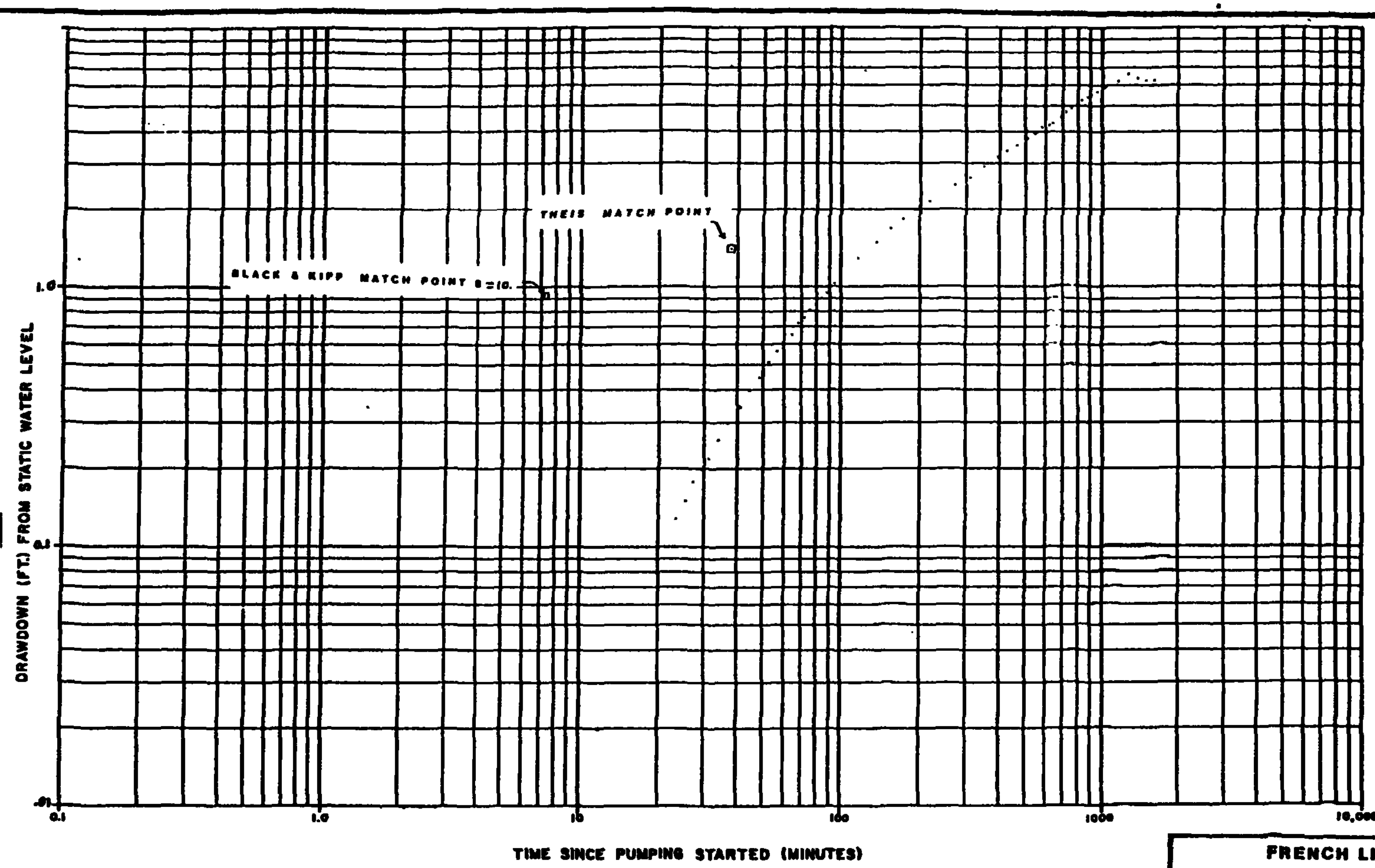

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FIGURE 6-12
WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI 10-1
OBSERVATION WELL: REI 11
DATE(S): 9/18/86 to 9/19/86

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

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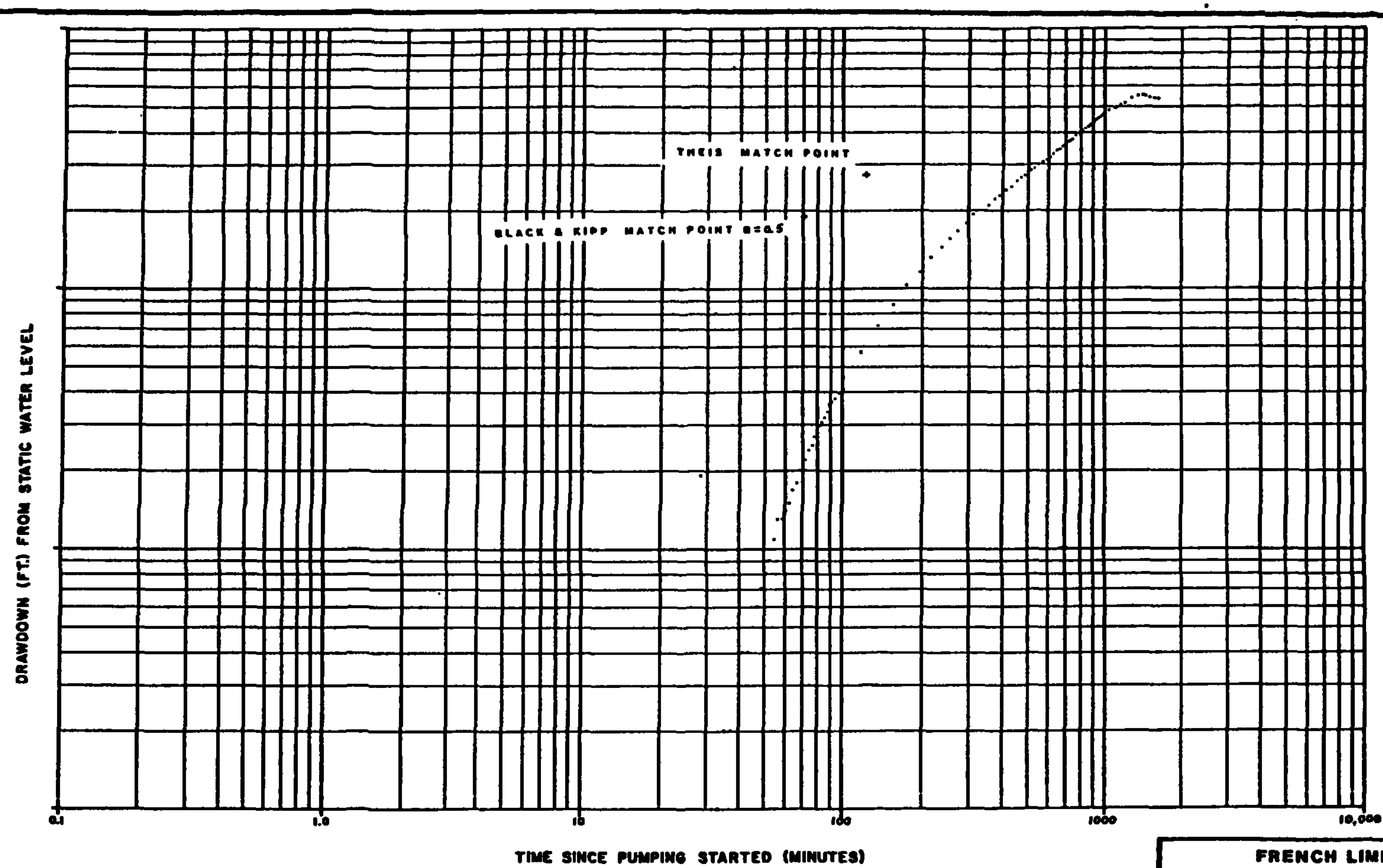

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FIGURE 6-13

WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI 10-1
OBSERVATION WELL: REI 3-4
DATE(S): 9/15/86 to 9/19/86

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.

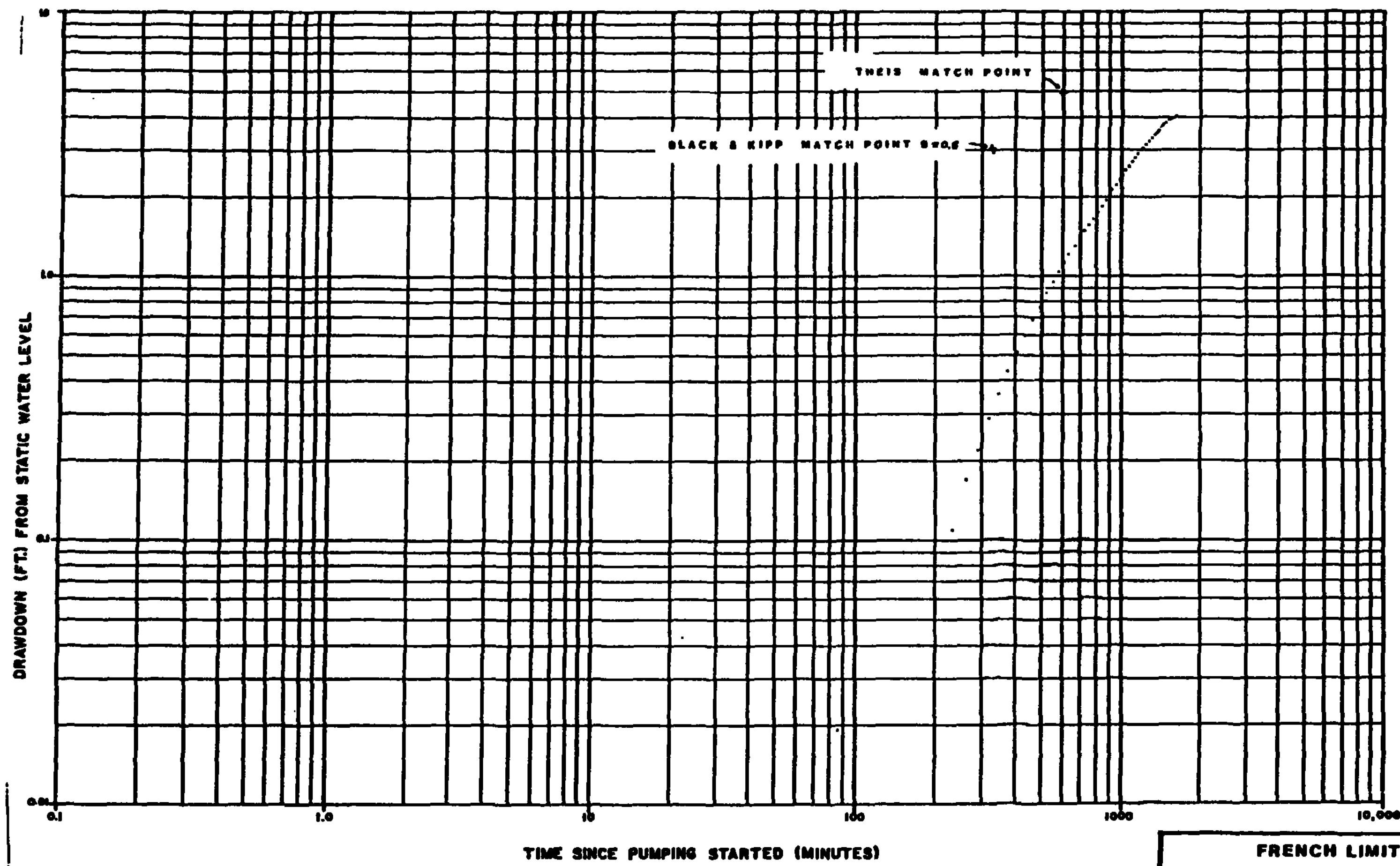

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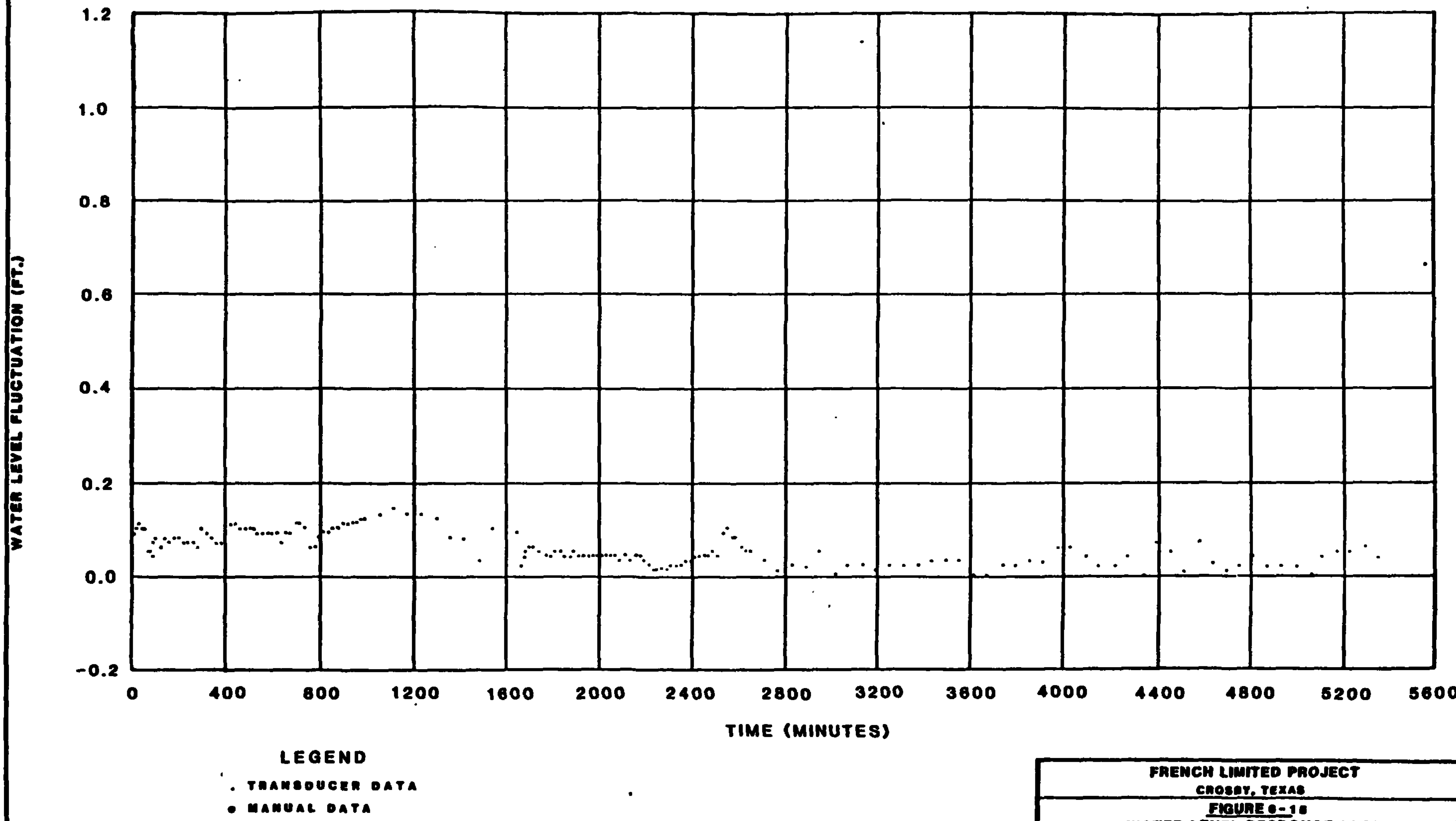
FIGURE 6-14
WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI 10-1
OBSERVATION WELL: REI 12-1
DATE(S): 9/18/86 to 9/19/86

PROJECT No. FR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



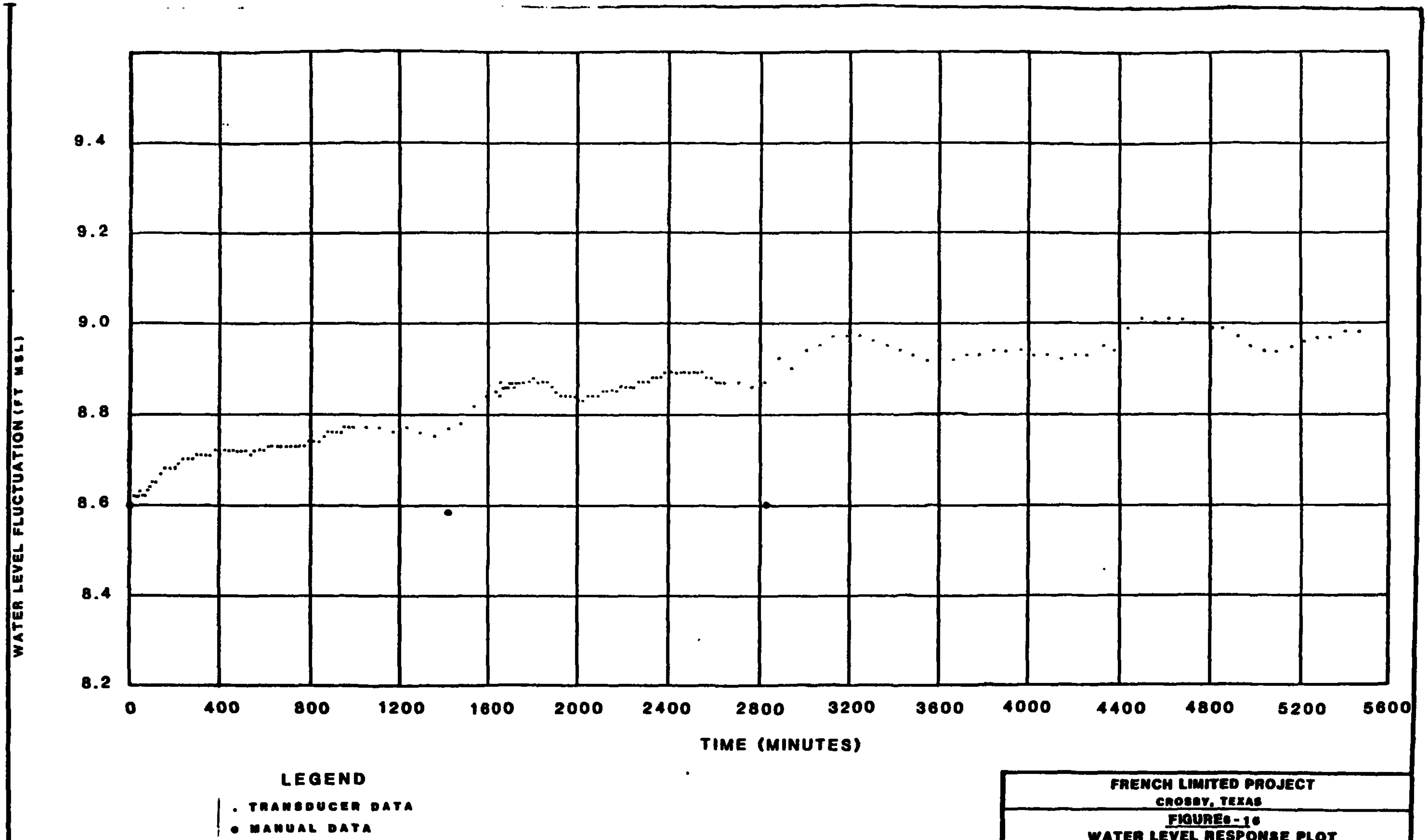
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-18
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI P10-2 PUMPED WELL: REI 10-1
DATE(S): 9/18/89 to 9/19/89 COMMENTS:

PROJECT No. PR 96-006 | DATE 11-26-96 | REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



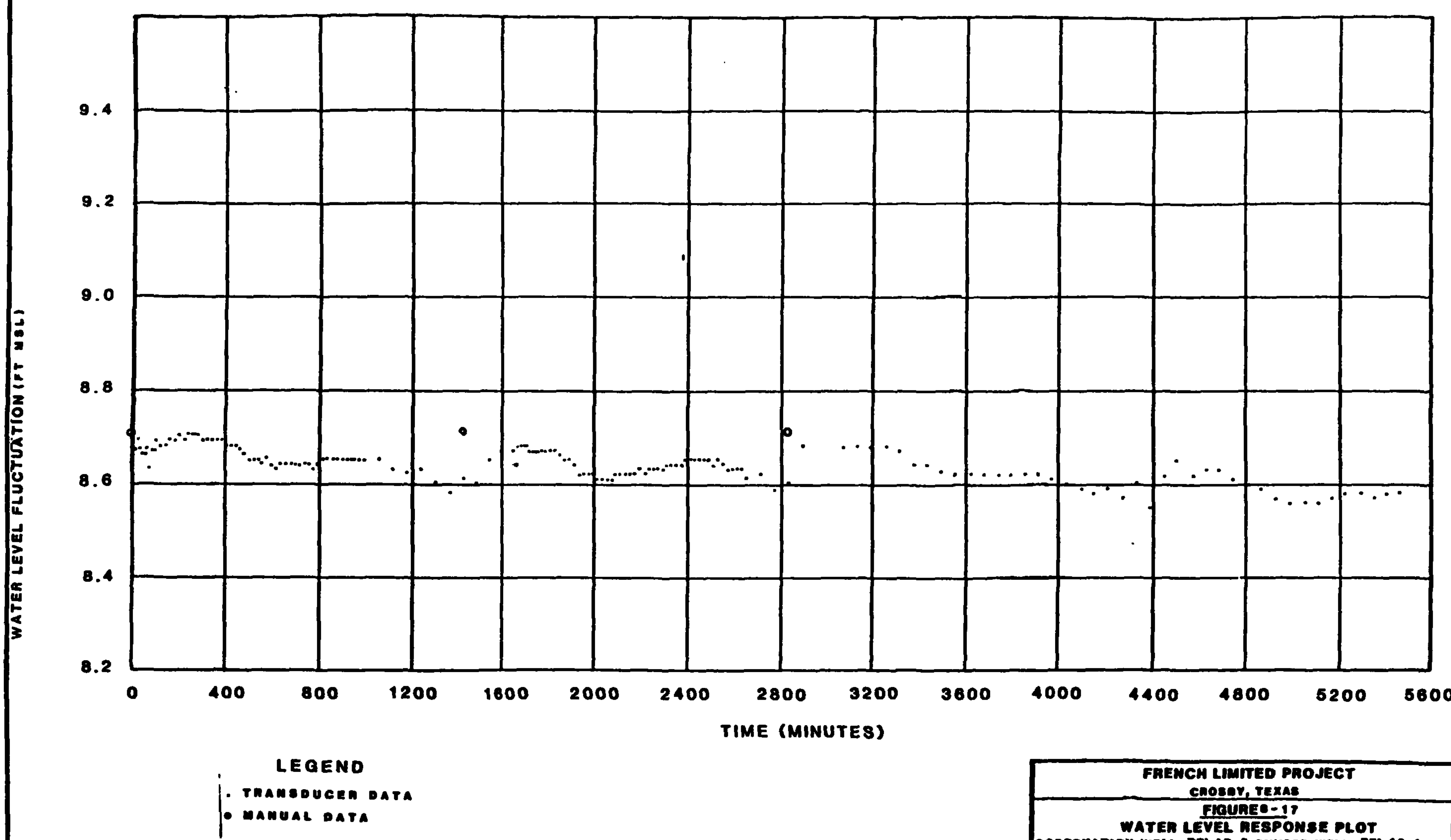
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-16
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 10-2 PUMPED WELL: REI 10-1
DATE(S): 9/15/86-9/19/86 COMMENTS:

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



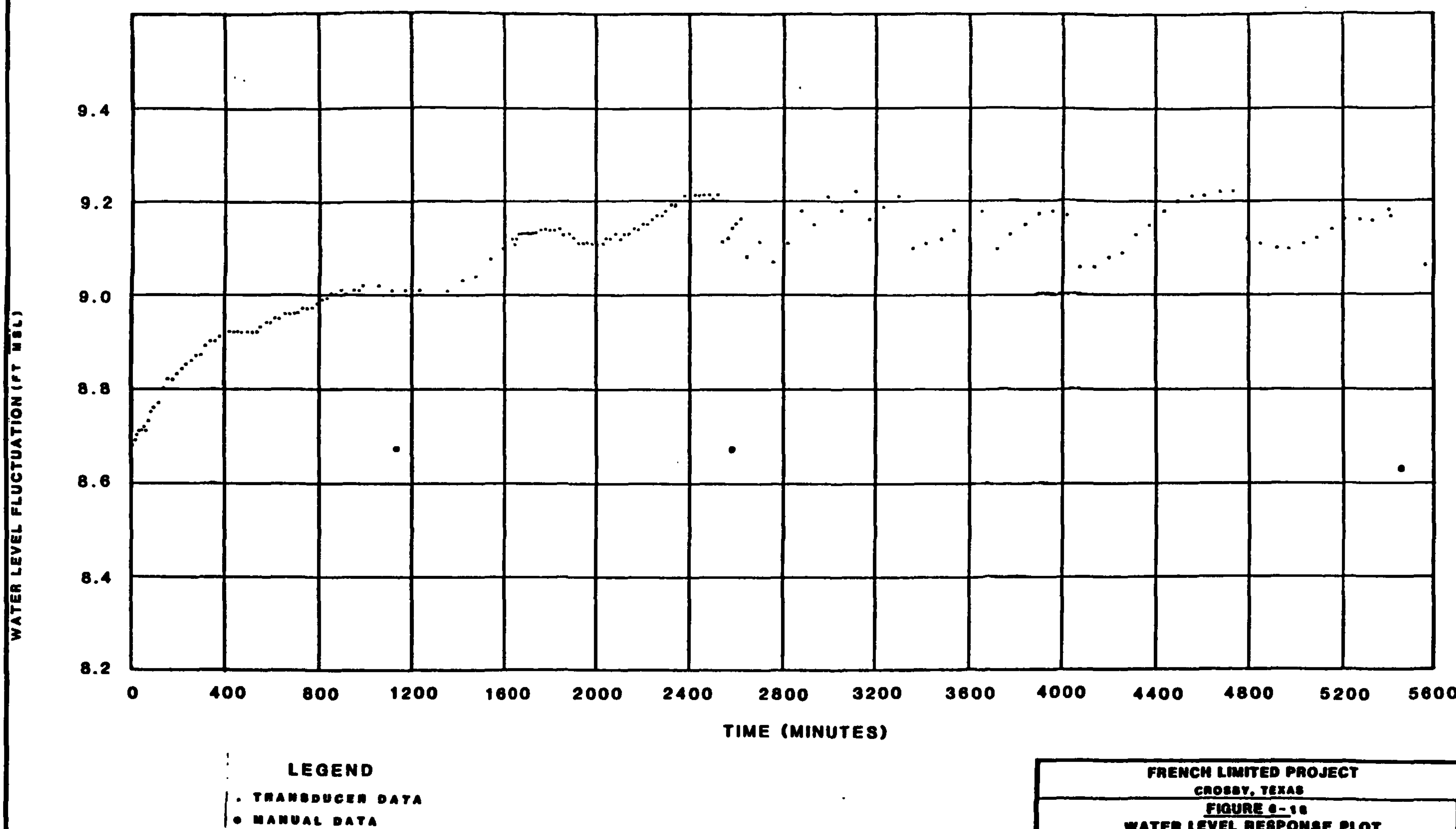
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-17
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 10-2 PUMPED WELL: REI 10-1
DATE(S): 9/15/86-9/19/86 COMMENTS:

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



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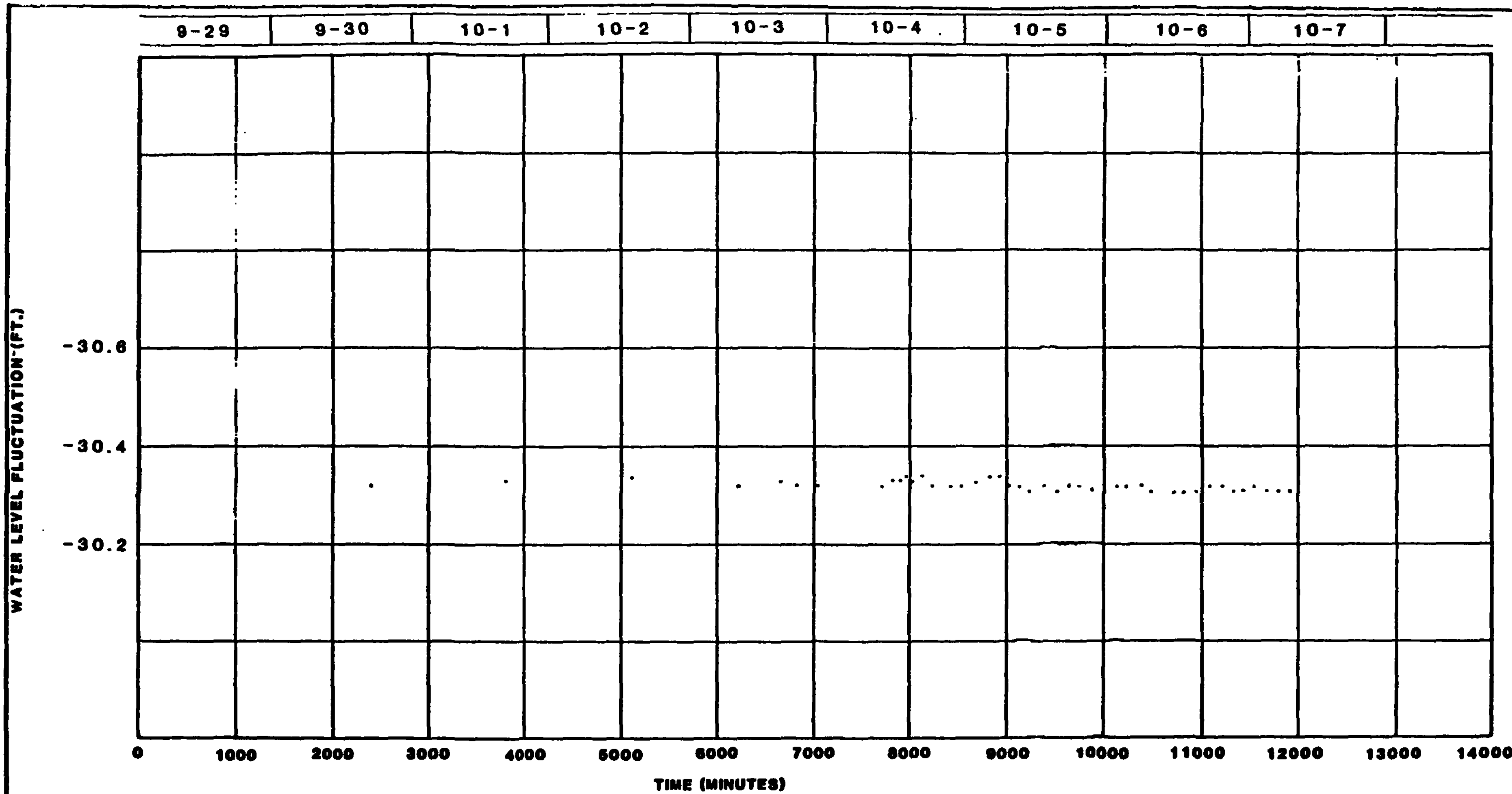
CROSBY, TEXAS

FIGURE 6-16
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 10-4 PUMPED WELL: REI 10-1
DATE(S): 9/15/86-9/19/86 COMMENTS:

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.

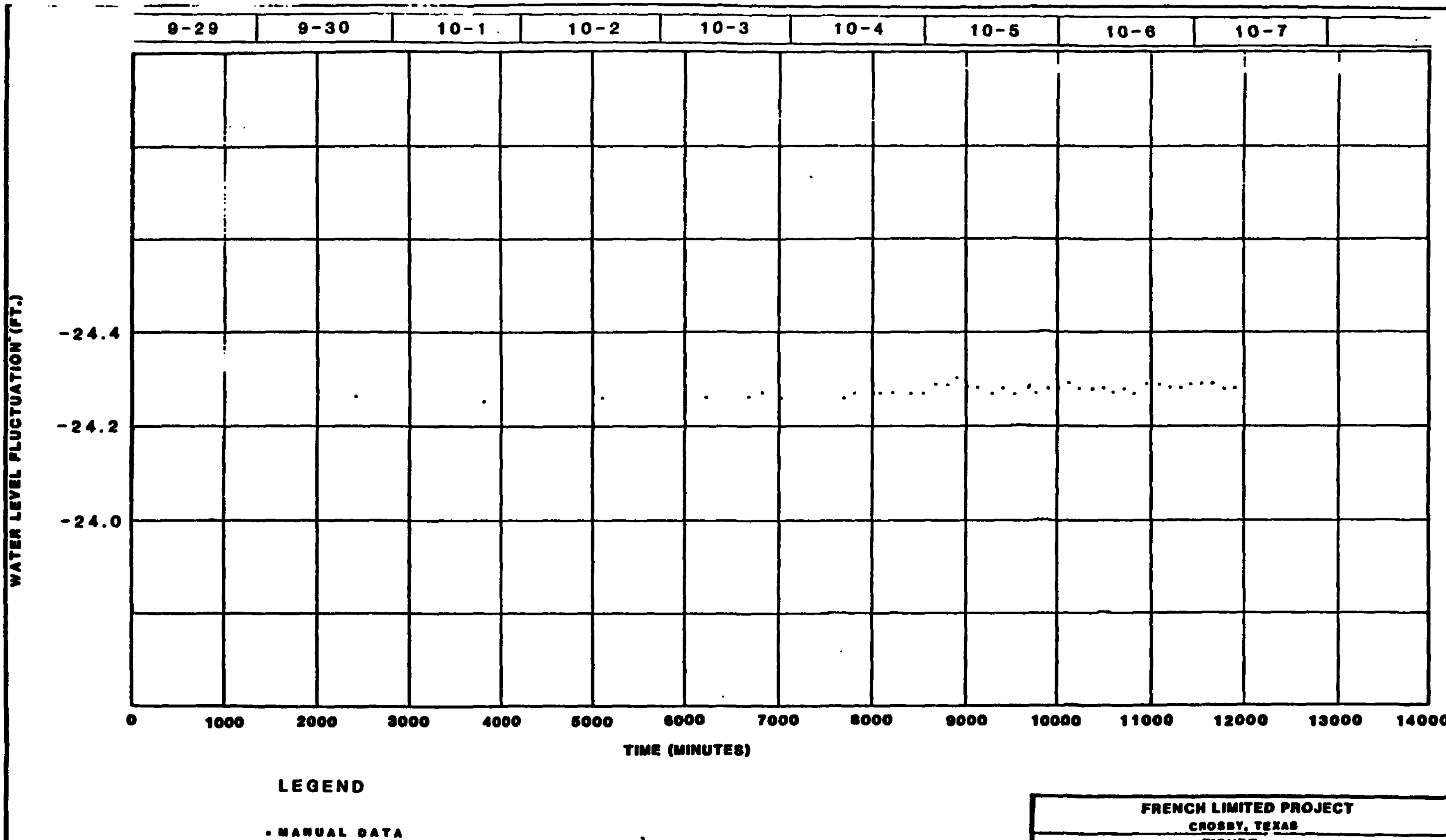


LEGEND

• MANUAL DATA

FRENCH LIMITED PROJECT CROSBY, TEXAS		
FIGURE 6-19 WATER LEVEL RESPONSE PLOT OBSERVATION WELL: RELP10-2 PUMPED WELL: PRE-TEST DATE(S): 9/29/86-10/7/86 COMMENTS:		
PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



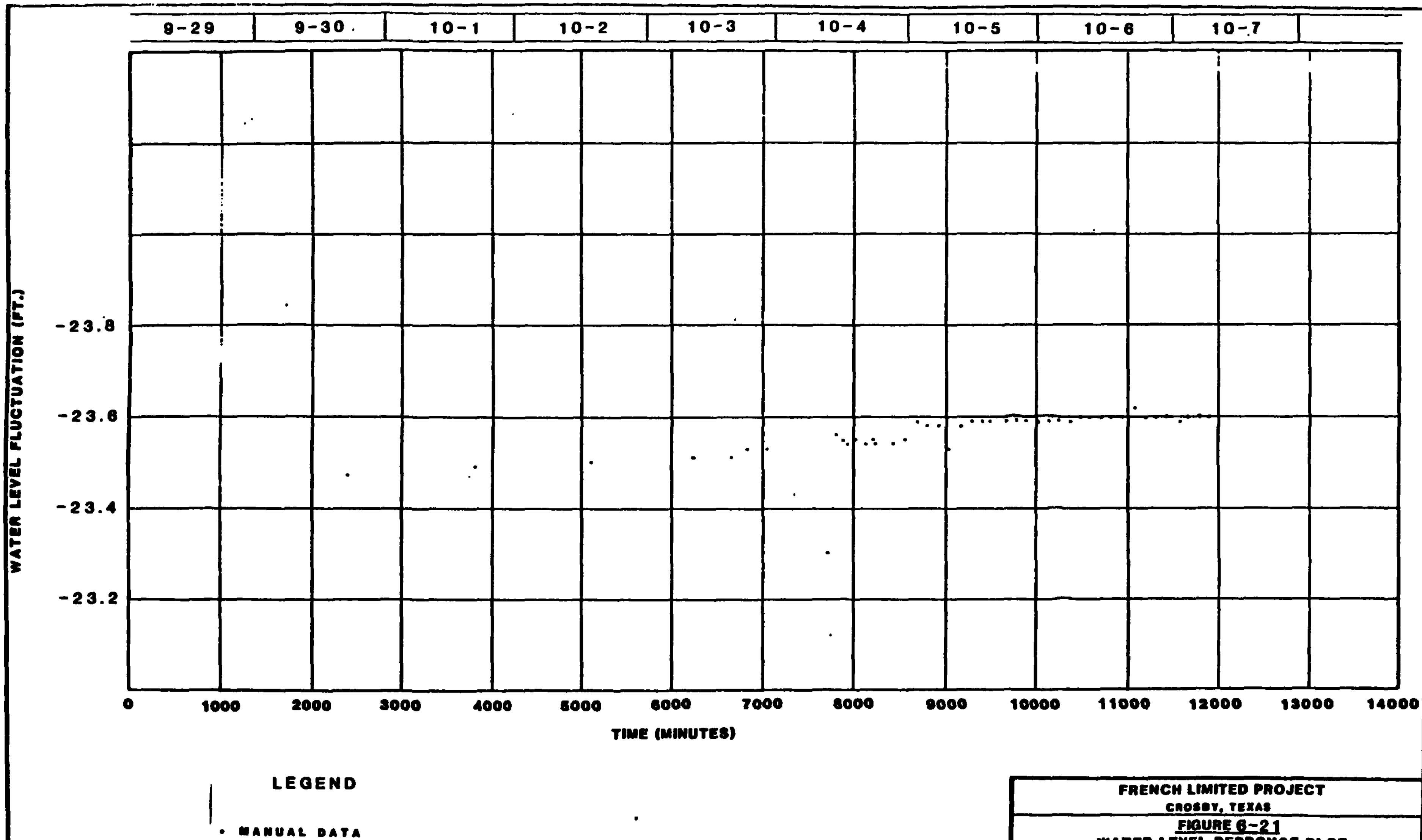
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-20
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI P10-3 PUMPED WELL: PRE-TEST
DATE(S): 9/29/86-10/7/86 COMMENTS:

PROJECT No. PR96-006	DATE 11-26-96	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



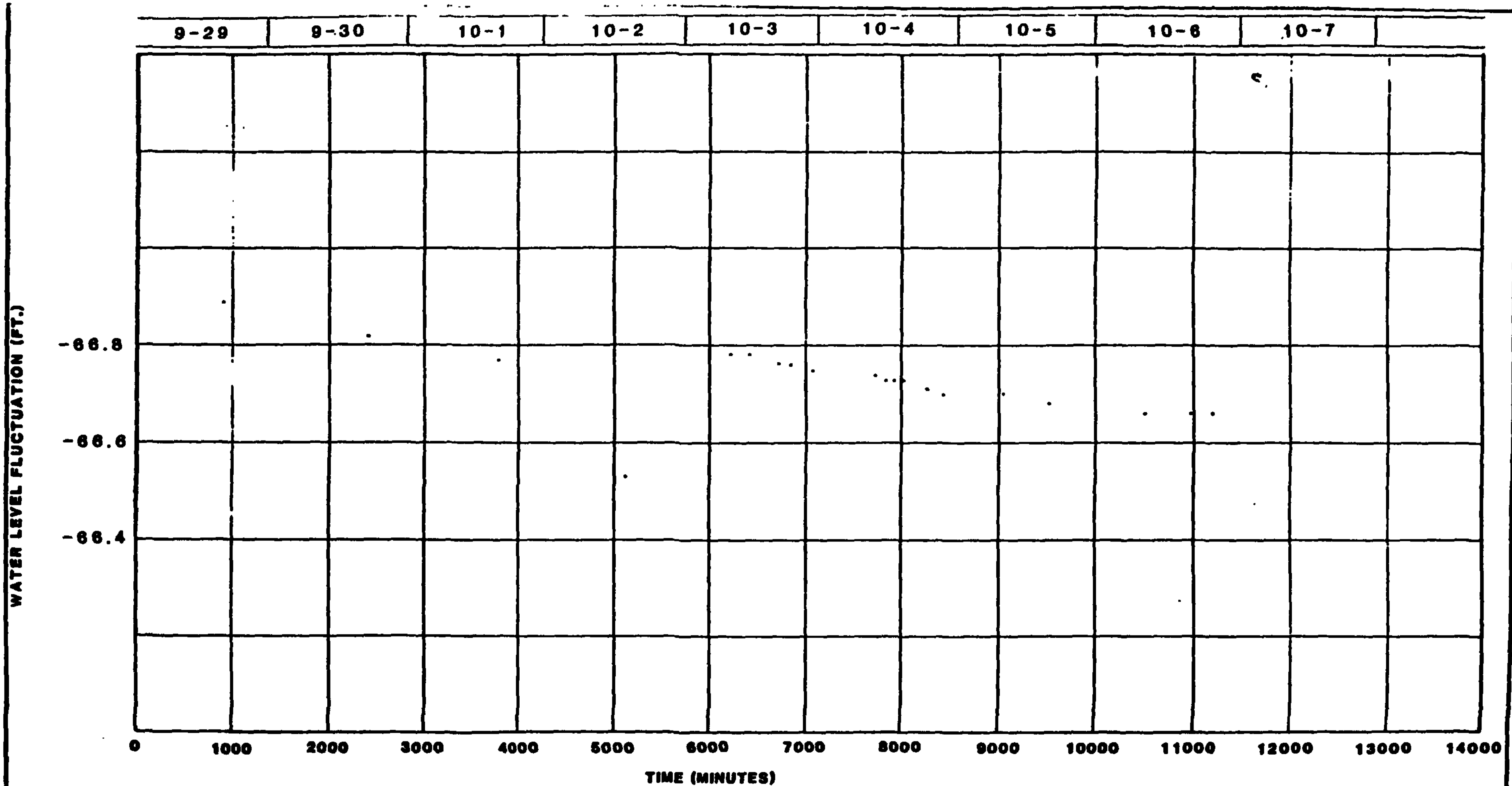
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-21
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: RELP10-4 PUMPED WELL: PRE-TEST
DATE(S): 9/29/86-10/7/86 COMMENTS:

PROJECT No. PR86-006	DATE 8-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



LEGEND

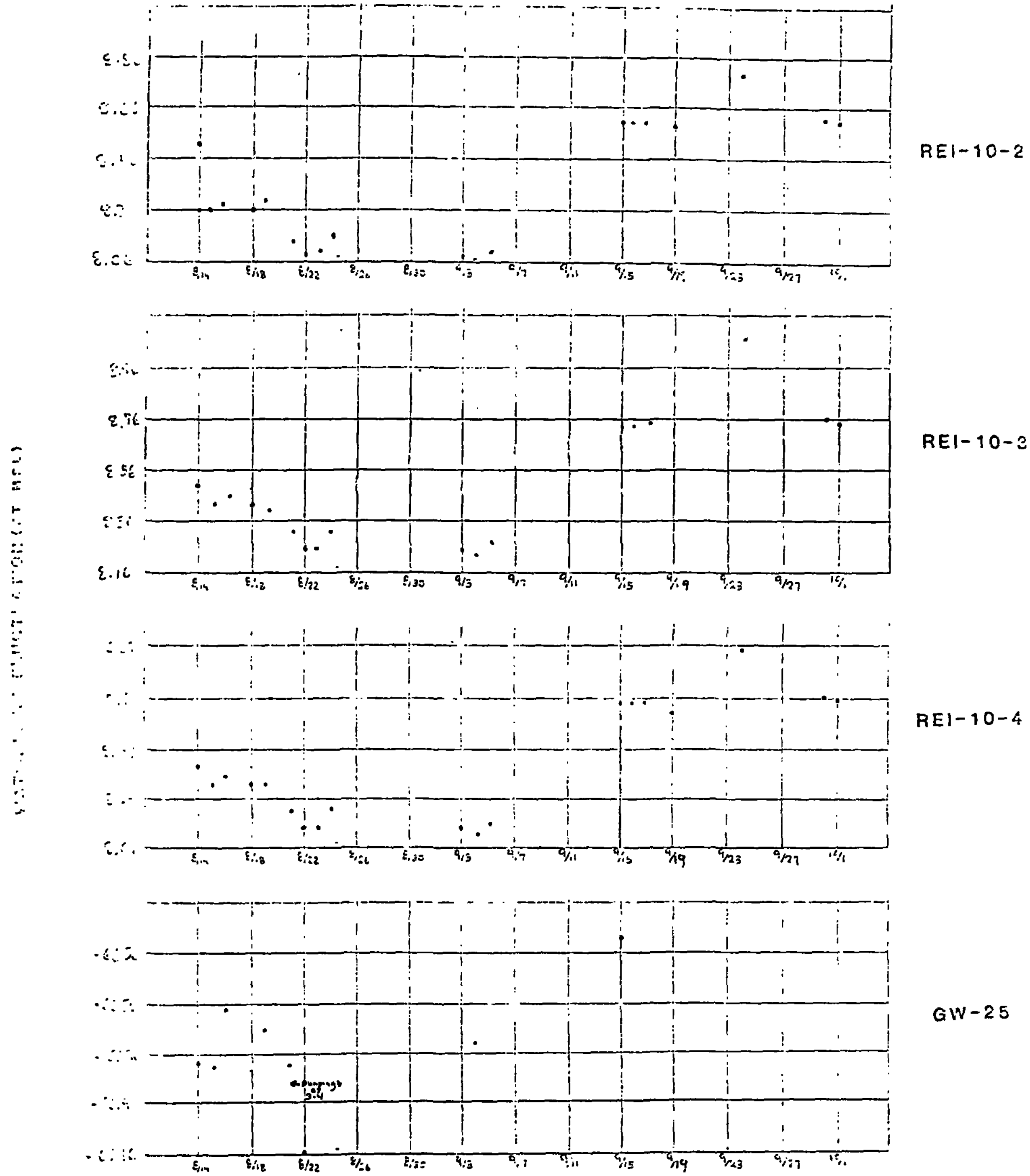
• MANUAL DATA

FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-22
WATER LEVEL RESPONSE PLOT
OBSERVATION WELL: REI 11 PUMPED WELL: PRE-TEST
DATE(S): 9/29/86-10/7/86 COMMENTS:

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



FRENCH LIMITED PROJECT
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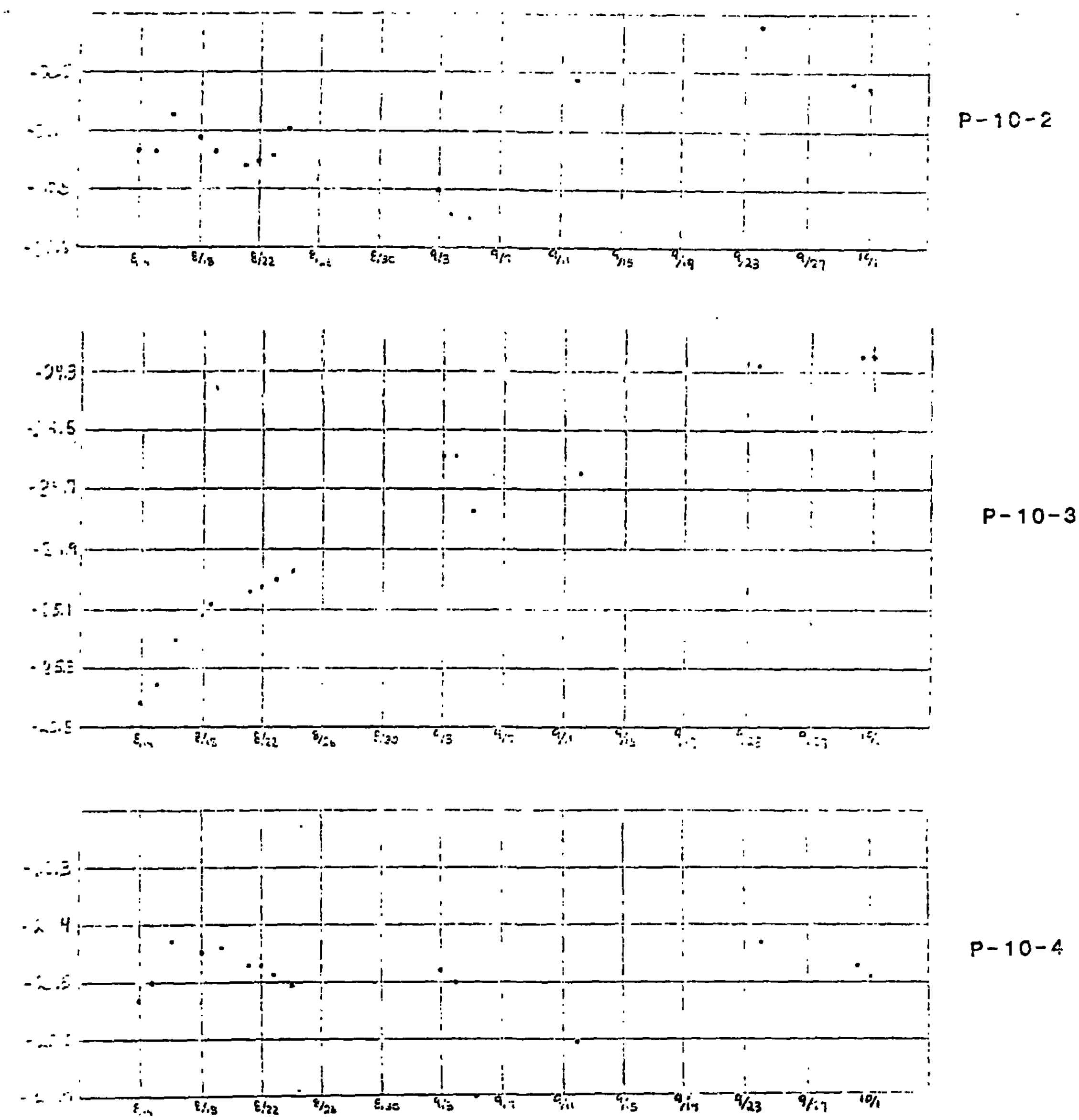
FIGURE 6-23
PRETEST
WATER LEVEL FLUCTUATIONS

PROJECT No. PR86-006 | DATE 11-26-86 | REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



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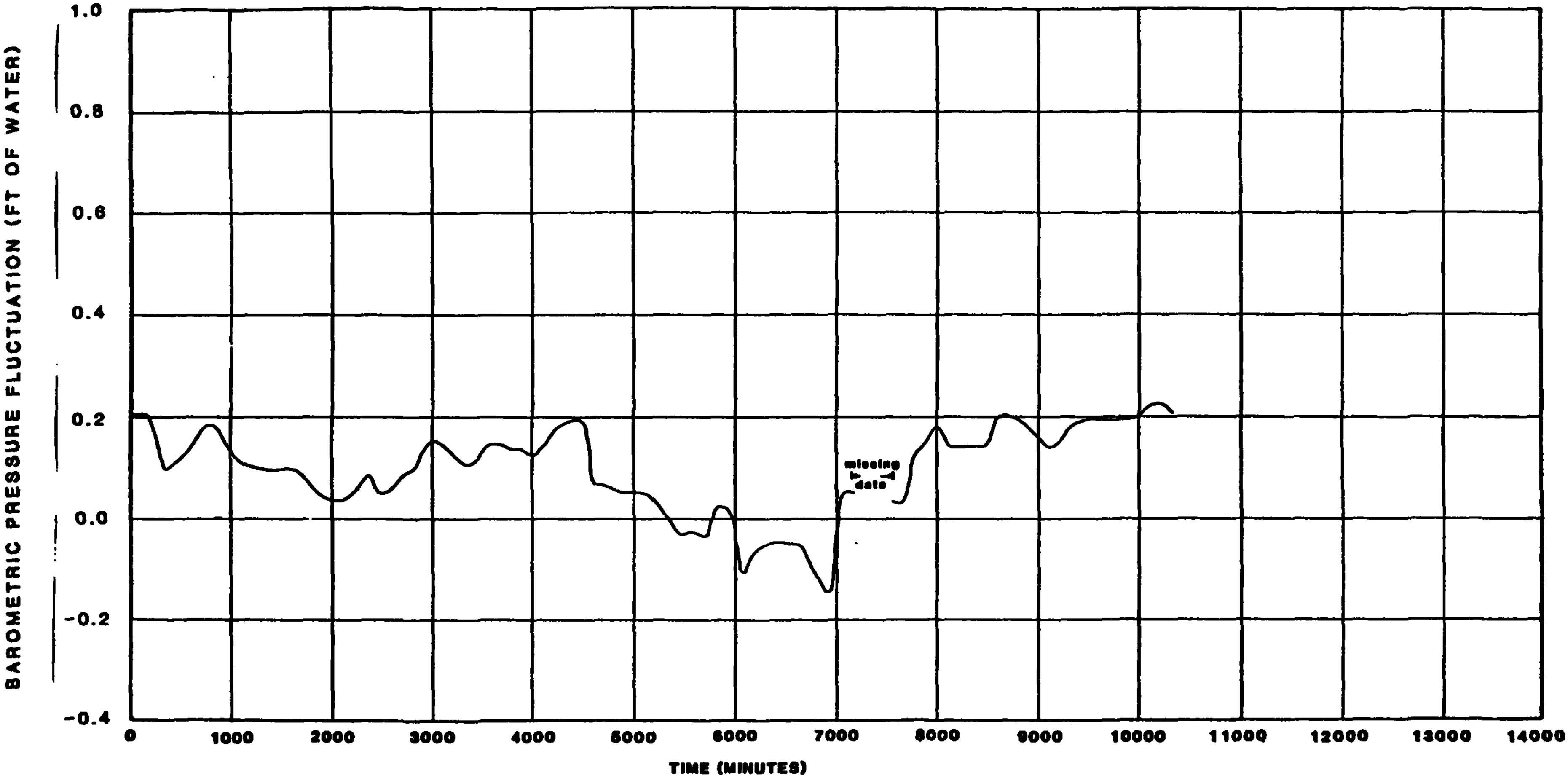
CROSBY, TEXAS

FIGURE6-24
PRETEST
WATER LEVEL FLUCTUATION

PROJECT No.	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

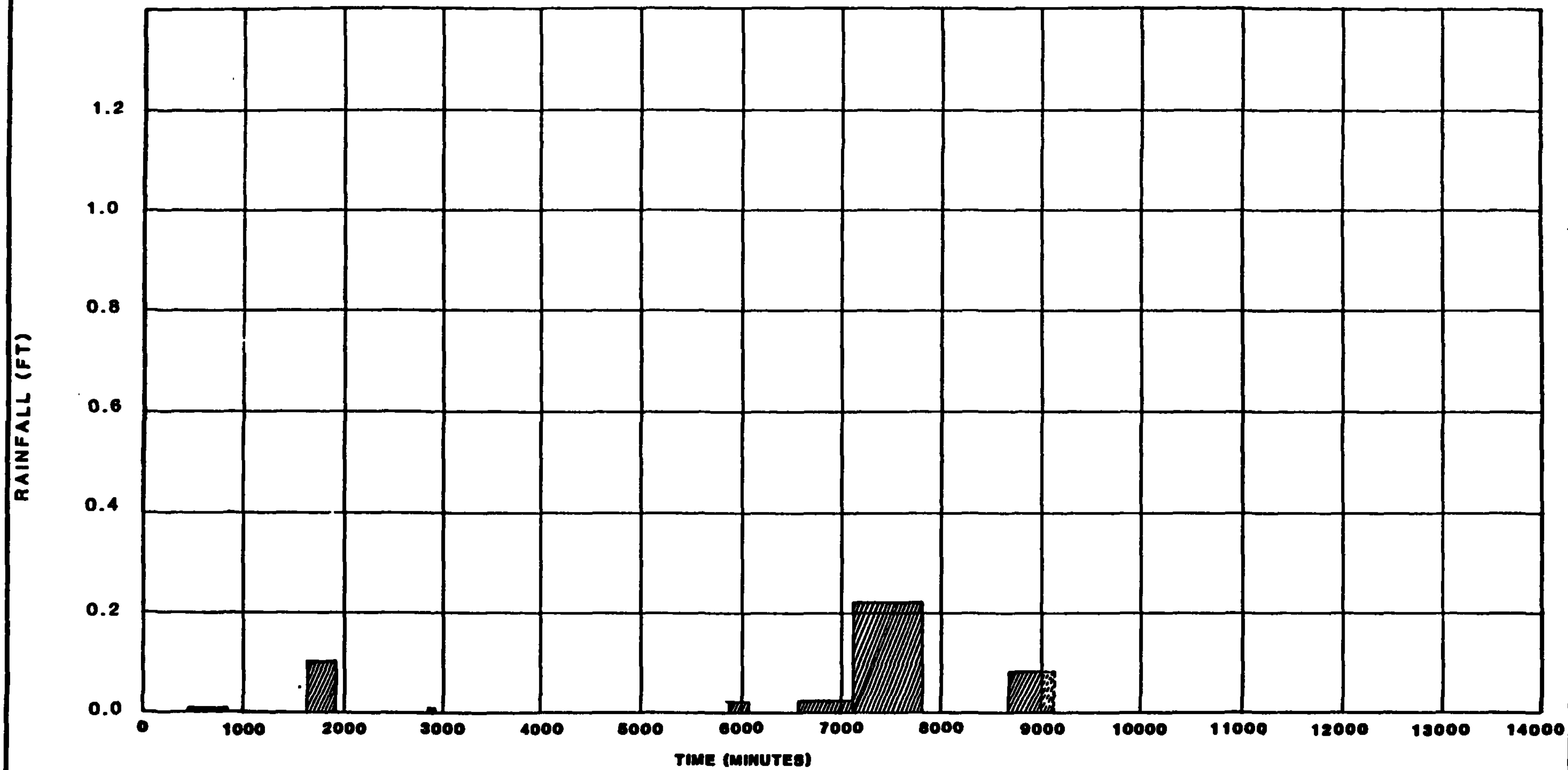
FIGURE 6-25

BAROMETRIC PRESSURE

DATE(S): 10/7/86-10/17/86 COMMENTS:

PROJECT No. FR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

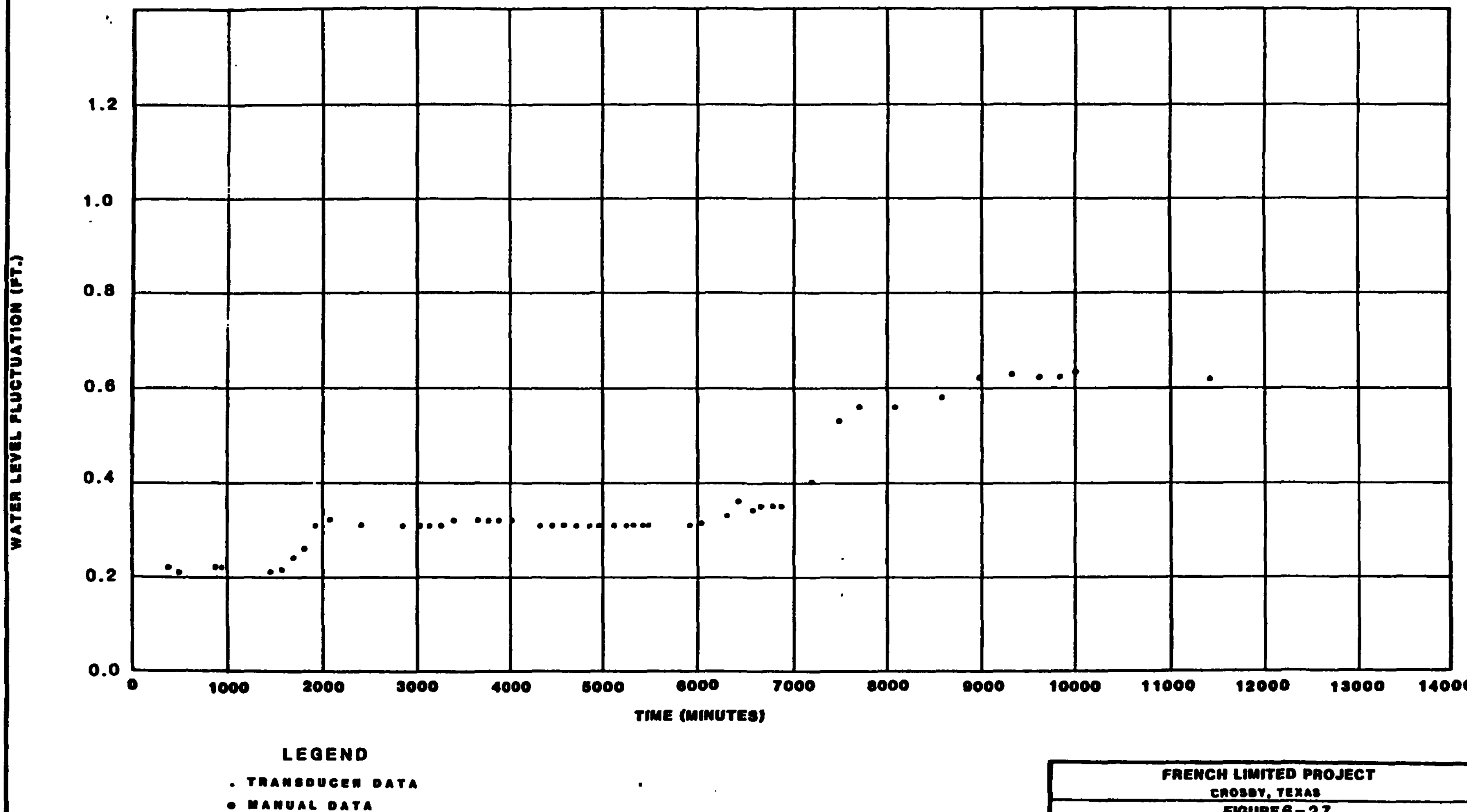
FIGURE 6-26

PRECIPITATION

DATE(S): 10/7/86-10/17/86 COMMENTS:

PROJECT No. FR86-006 | DATE 11-26-86 | REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



FRENCH LIMITED PROJECT

CROSBY, TEXAS

FIGURE 6-27

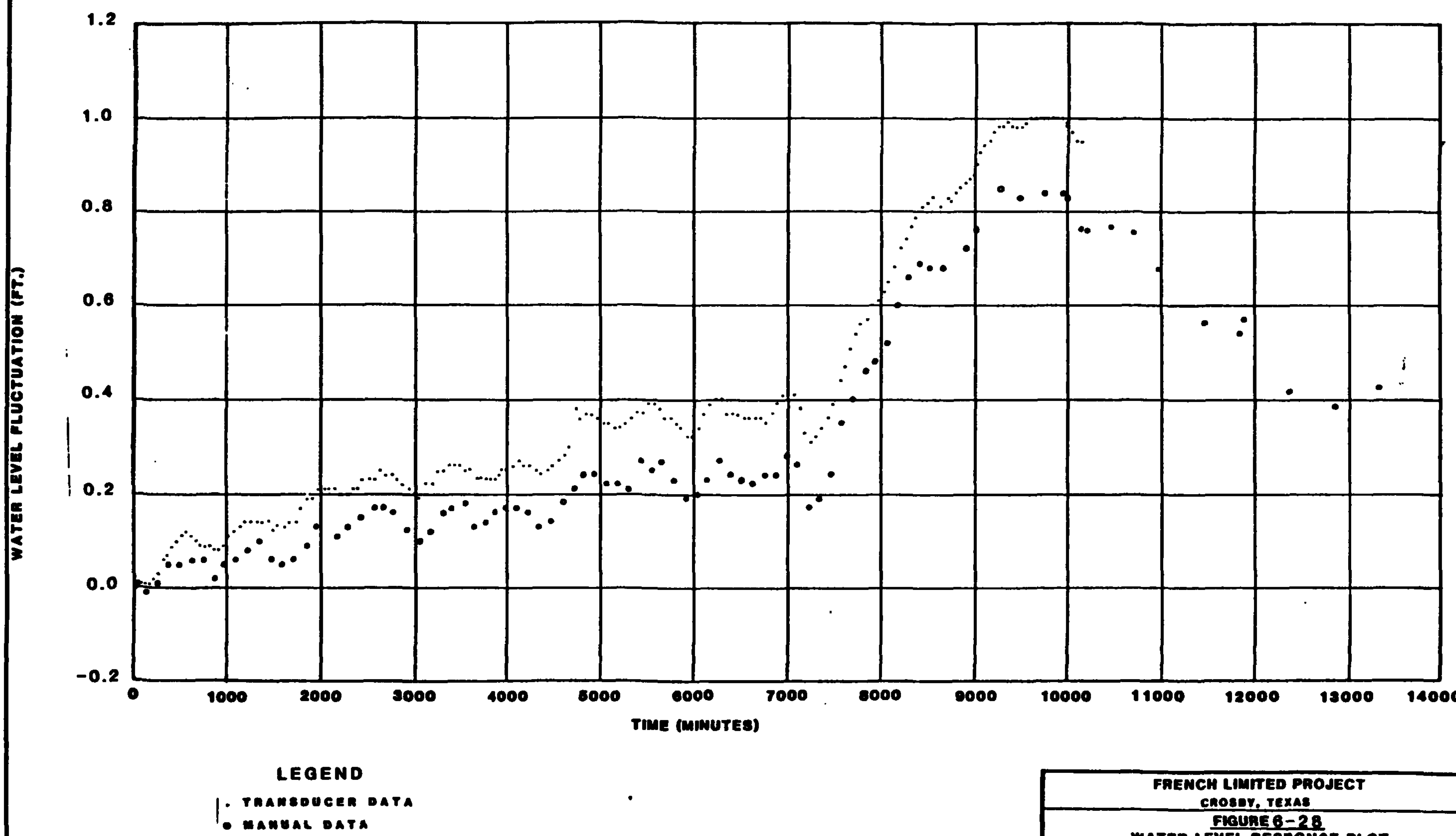
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: LAGOON PUMPED WELL: REI 10-1

DATE(S): 10/7-17/86 COMMENTS:

PROJECT No. PRF6-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

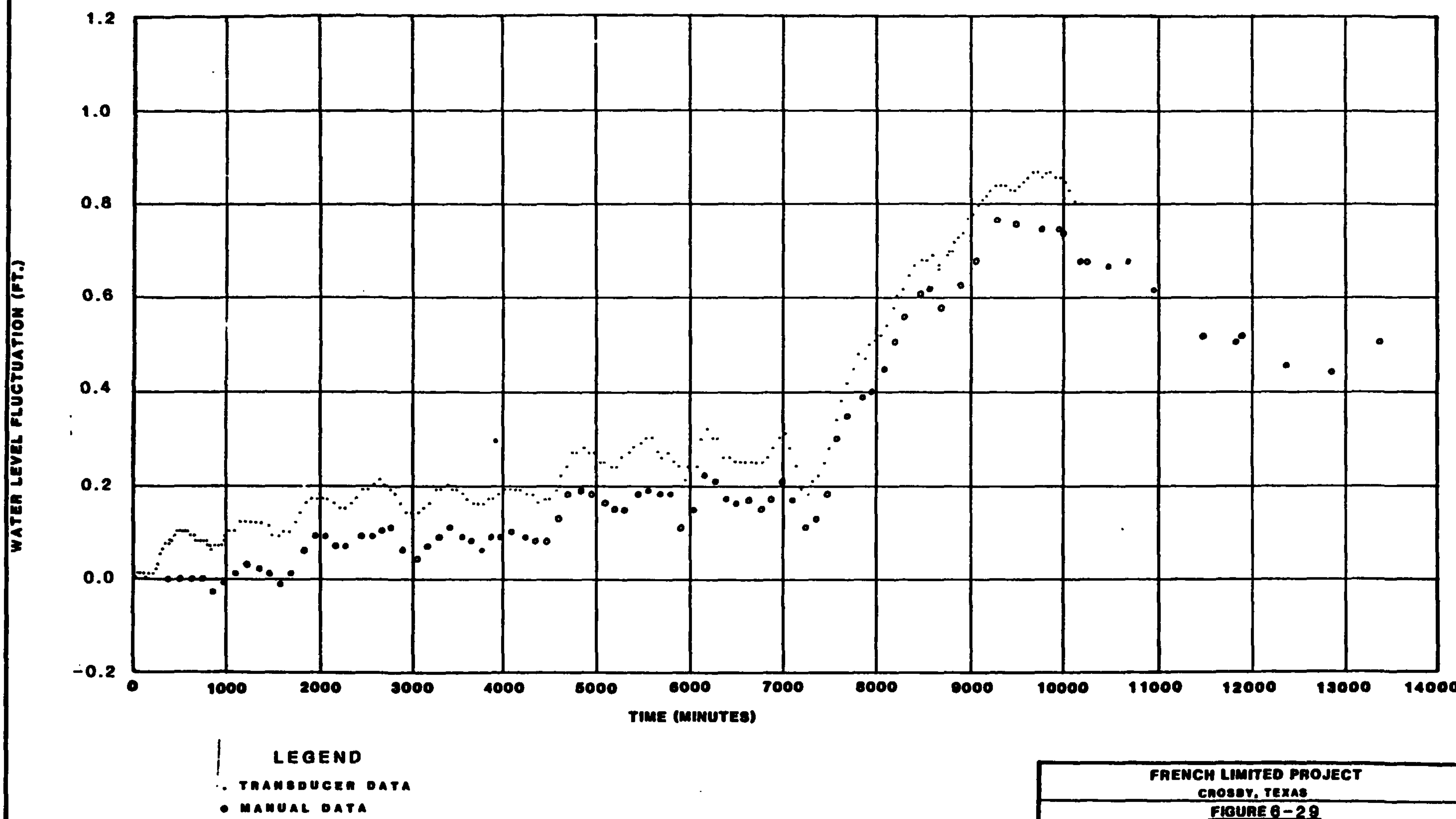
FIGURE 6-28

WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 10-2 PUMPED WELL: REI 10-1
DATE(S): 10/7-17/88 COMMENTS:

PROJECT No. FRE6-001	DATE 11-14-88	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



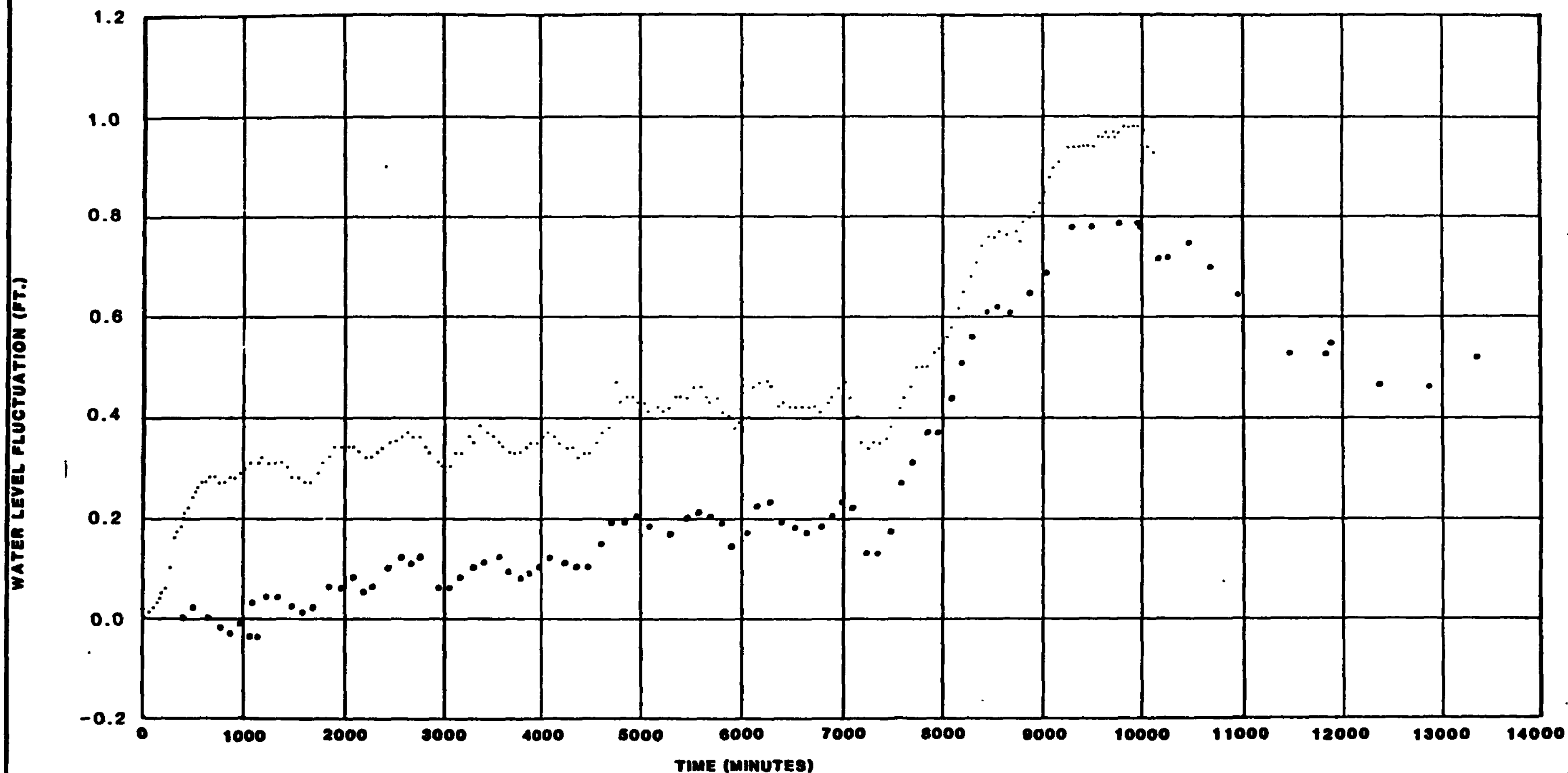
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-29
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 10-3 PUMPED WELL: REI 10-1
DATE(S): 10/7-17/86 COMMENTS:

PROJECT No. PR86-006 | DATE 11-14-86 | REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



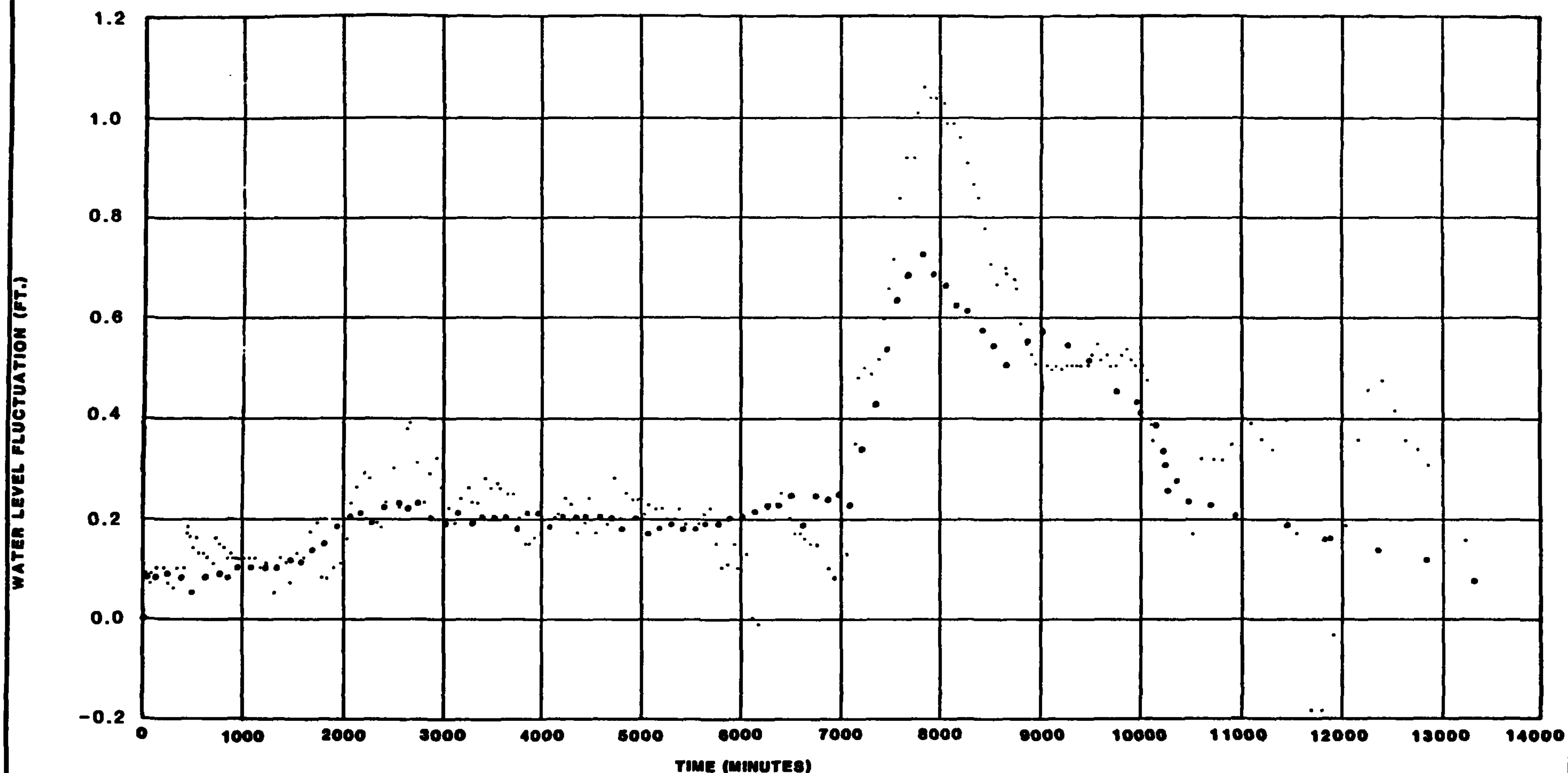
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-30
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 10-4 PUMPED WELL: REI 10-1
DATE(S): 10/7-17/86 COMMENTS:

PROJECT No. RCM-001	DATE 11-14-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



LEGEND

. TRANSDUCER DATA

● MANUAL DATA

FRENCH LIMITED PROJECT

CROSBY, TEXAS

FIGURE 6-31

WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI P10-2 PUMPED WELL: REI 10-1

DATE(S): 10/7-17/86 COMMENTS:

PROJECT No. AH86-006 | DATE 11-14-86 | REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.

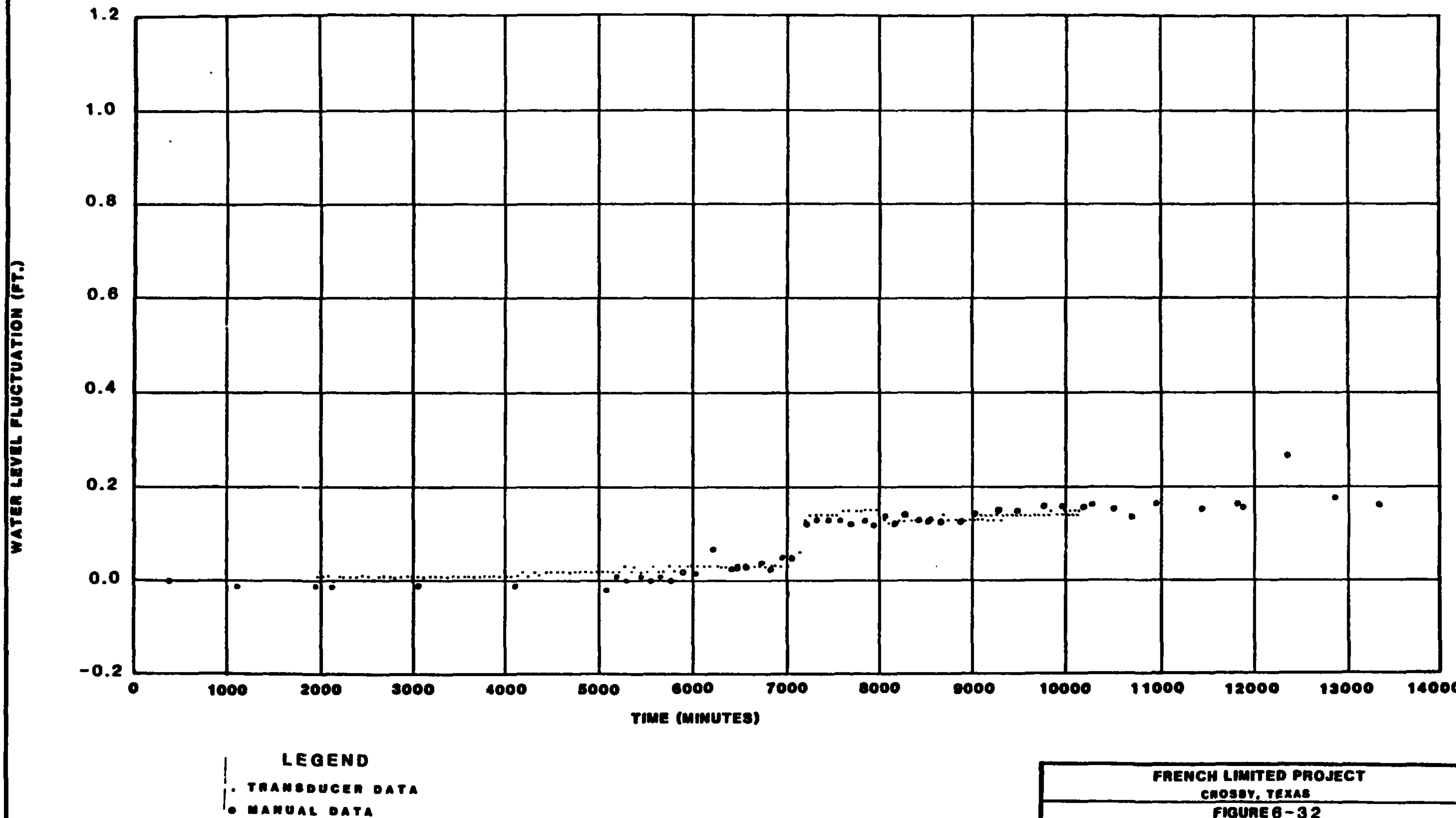


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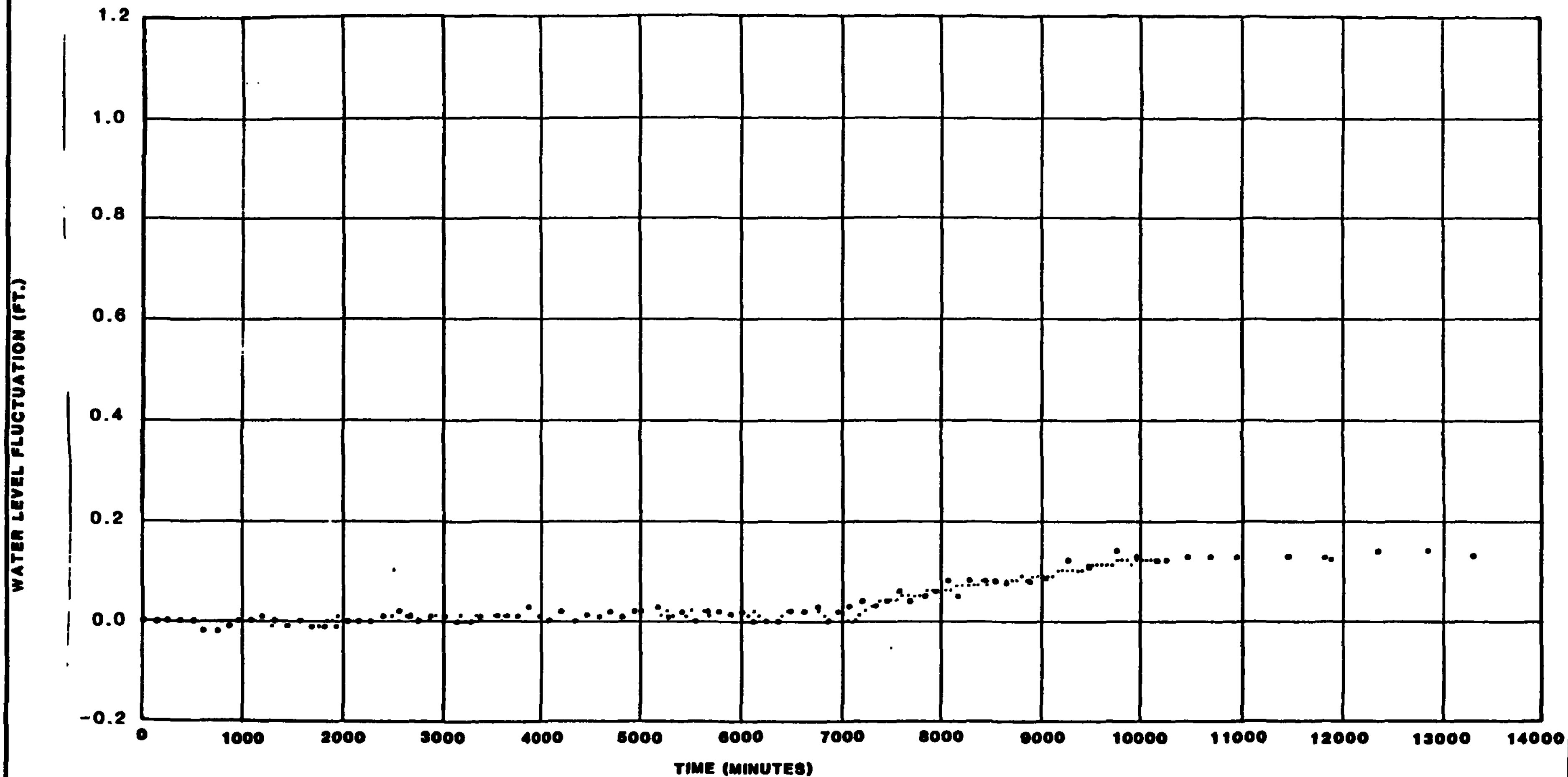
FIGURE 6-32
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI P10-2 PUMPED WELL: REI 10-1
DATE(S): 10/7-17/86, COMMENTS:

PROJECT No. PK 86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



LEGEND

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● MANUAL DATA

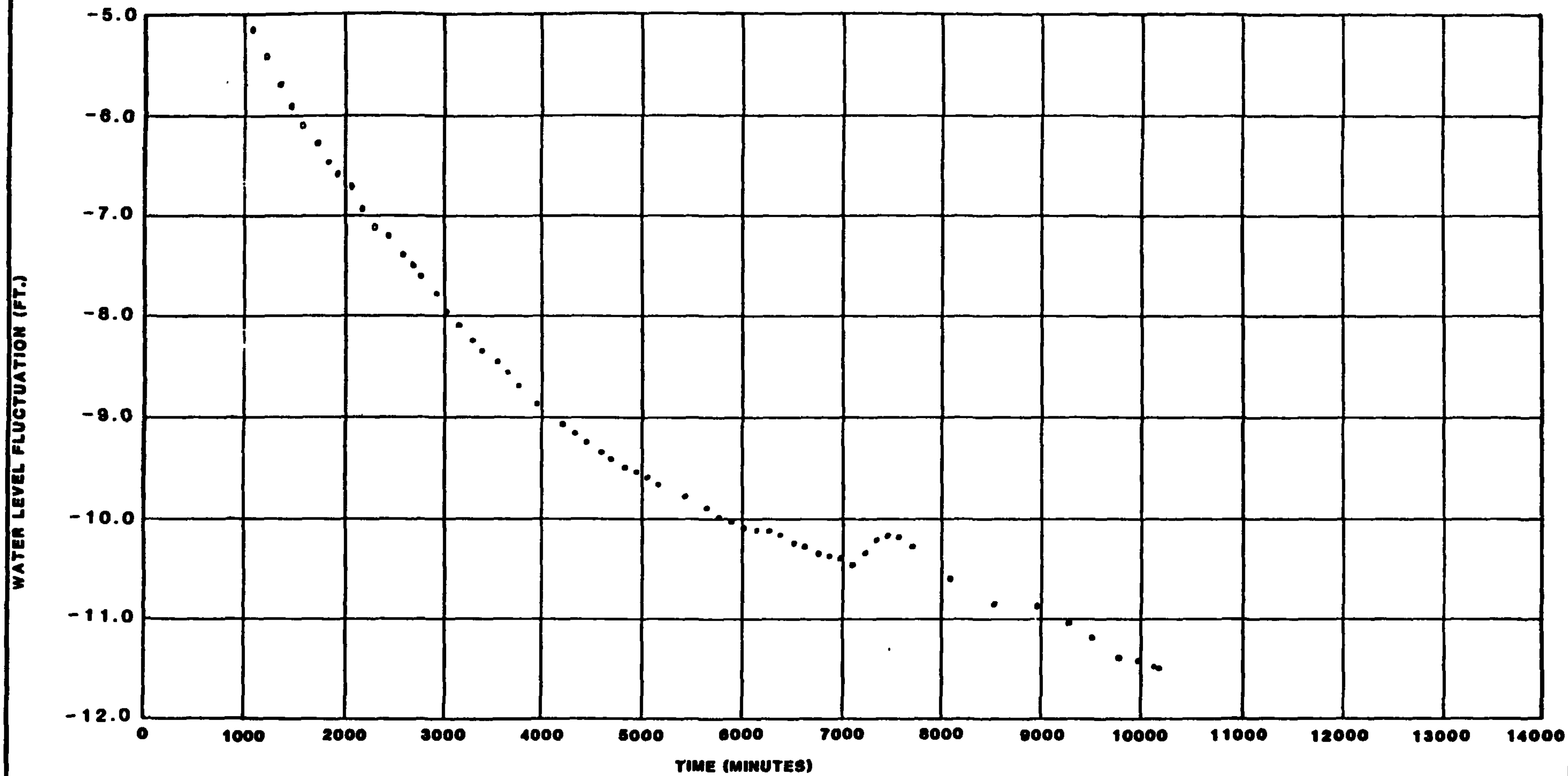
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-33
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI P10-4 PUMPED WELL: REI 10-1
DATE(S): 10/7-17/86 COMMENTS:

PROJECT No.	DATE	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



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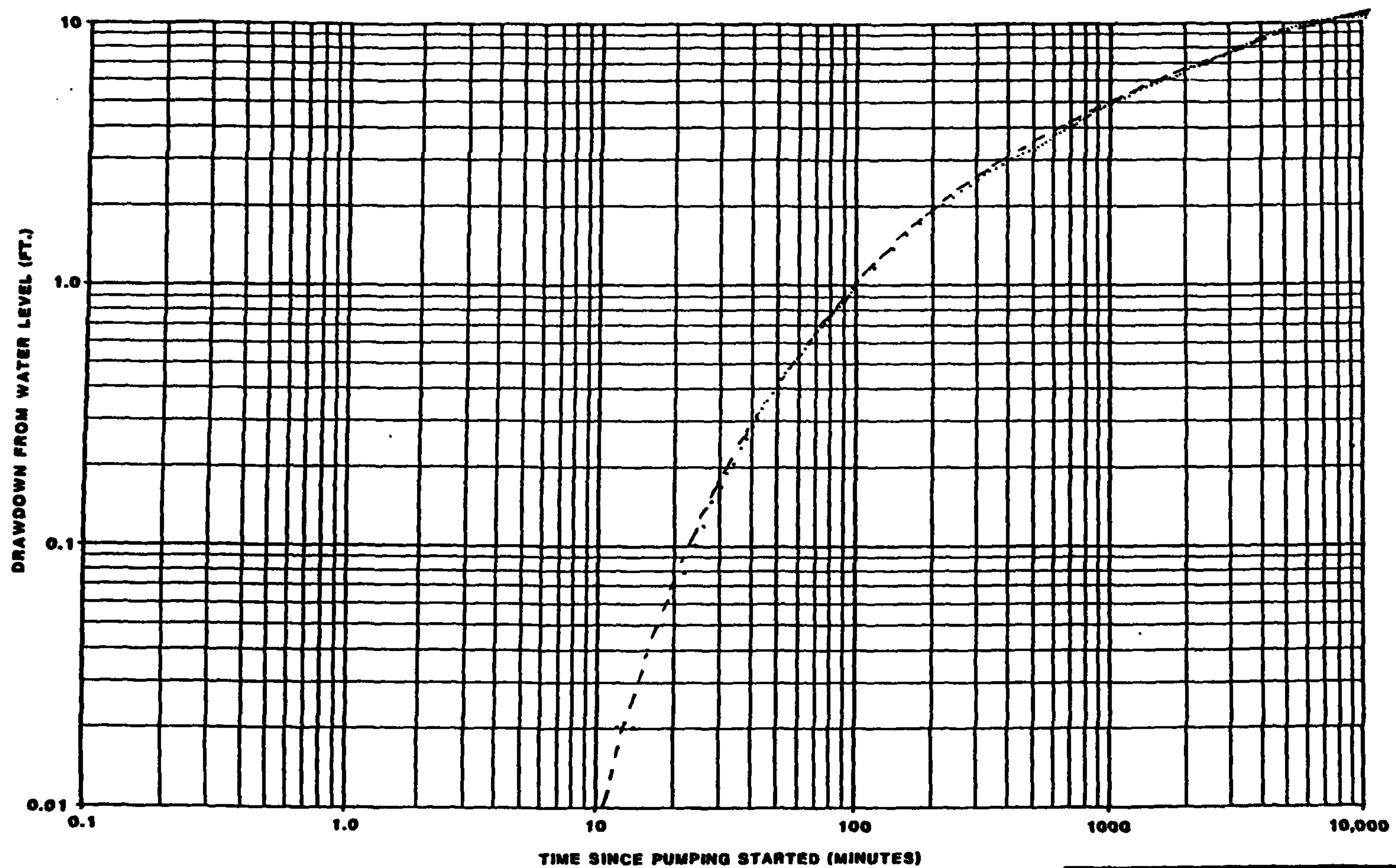
● MANUAL DATA

FRENCH LIMITED PROJECT CROSBY, TEXAS		
FIGURE 6-34 WATER LEVEL RESPONSE PLOT OBSERVATION WELL: REI 11 PUMPED WELL: REI 10-1 DATE(S): 10/7-17/86 COMMENTS:		
PROJECT No. FR86-006	DATE 11-14-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



LEGEND

. TRANSDUCER DATA

• MANUAL DATA

THEIS CURVE

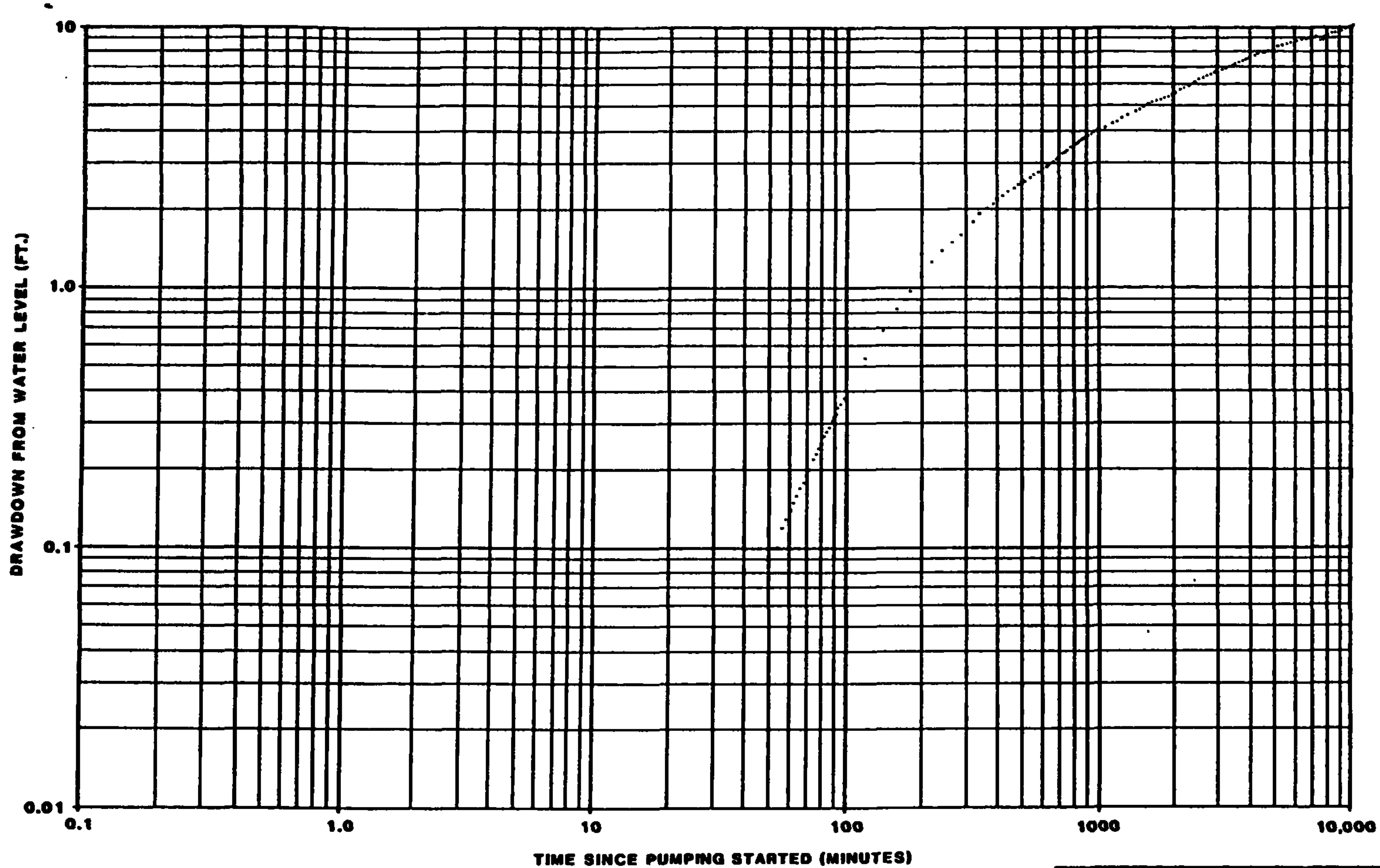
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-35
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 11 PUMPED WELL: REI 10-1
DATE(S): 10/7-17/86 COMMENTS:

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



LEGEND

. TRANSDUCER DATA

• MANUAL DATA

FRENCH LIMITED PROJECT

CROSBY, TEXAS

FIGURE 6-36

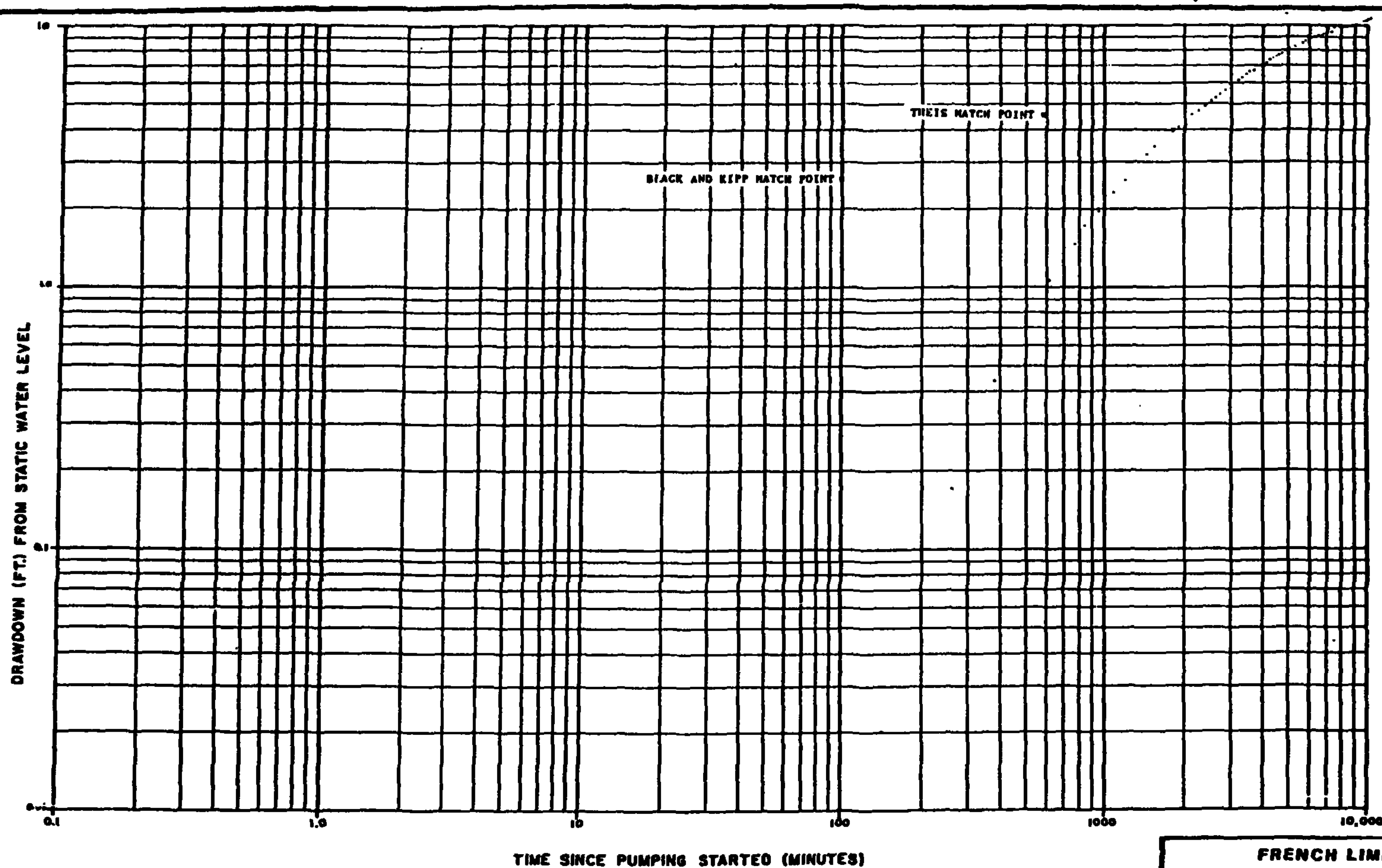
WATER LEVEL RESPONSE PLOT

OBSERVATION WELL: REI 3-4 PUMPED WELL: REI 10-1

DATE(S): 10/7-17/86 . COMMENTS:

PROJECT No. PRFL-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER, CO.



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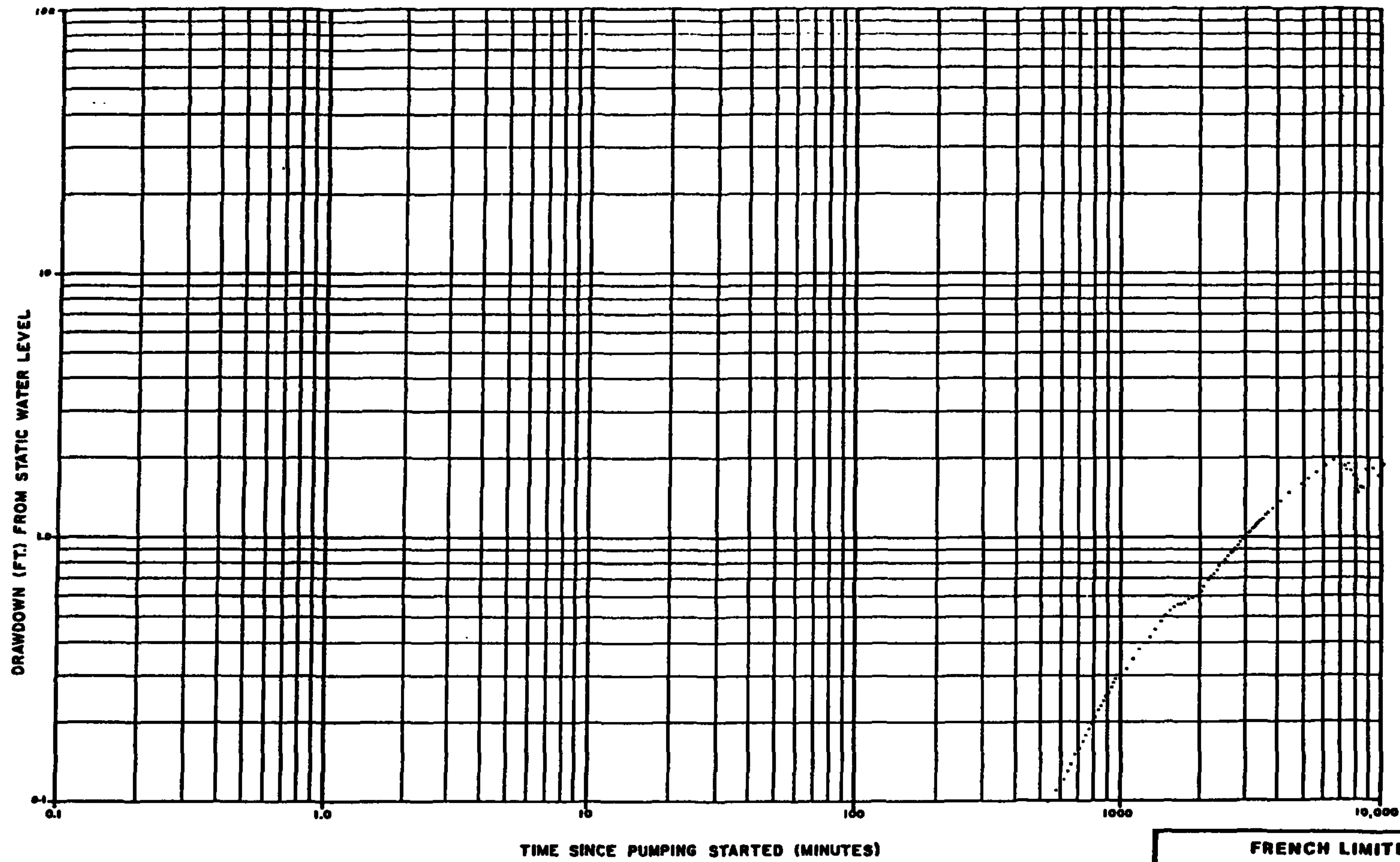
CROSBY, TEXAS

FIGURE 6-37
WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI 10-1
OBSERVATION WELL: REI 12-1
DATE(S): 10/7-17/88

PROJECT No. PK96-006	DATE 11-26-88	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



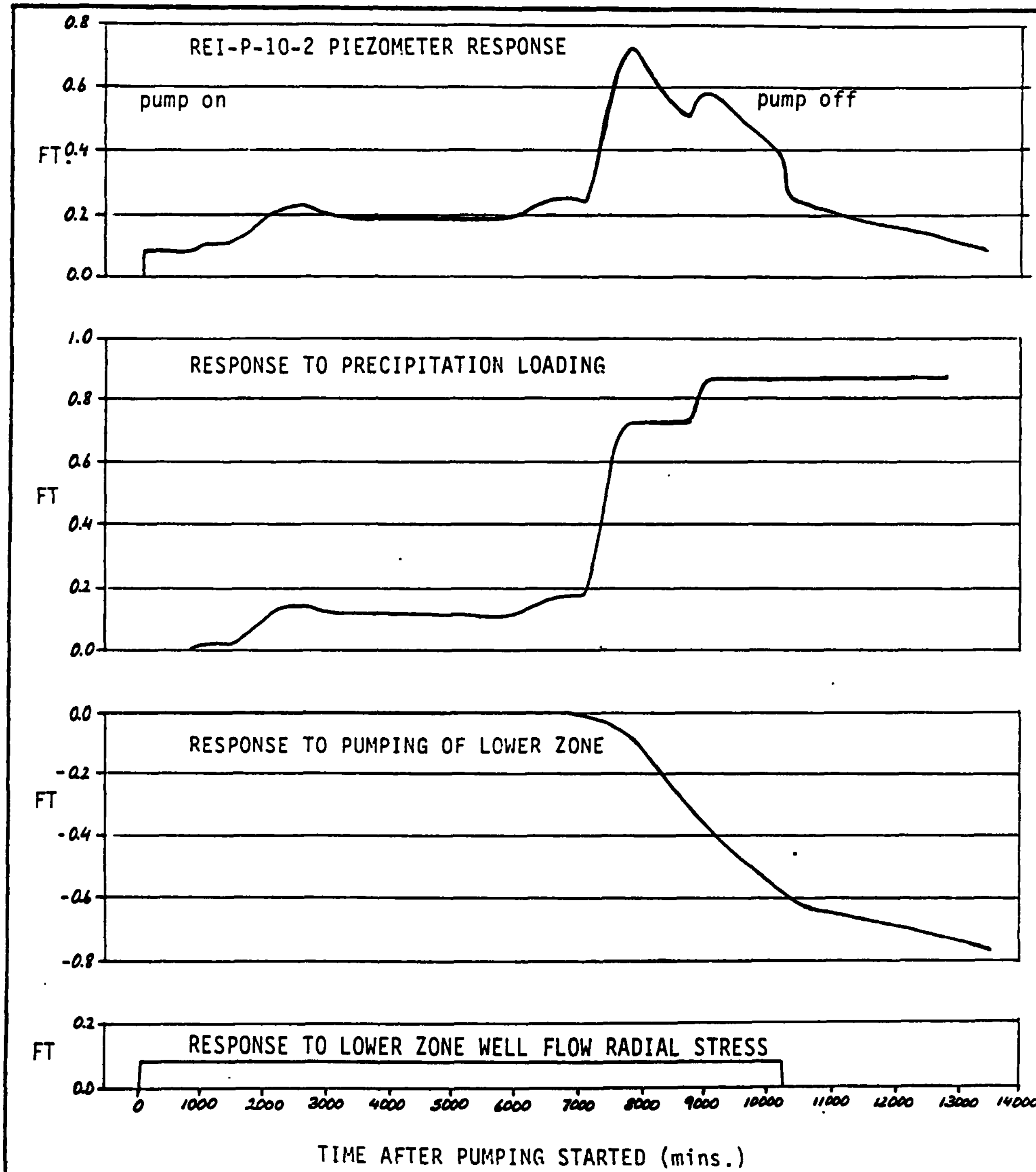
FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-38
WATER LEVEL RESPONSE PLOT

PUMPED WELL: REI 10-1
OBSERVATION WELL: REI 7
DATE(S): 10/7-17/86

PROJECT No. FR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-39

RESPONSE OF REI-P-10-2 PIEZOMETER
TO SUPERIMPOSED STRESSES DURING
THE REI-10-1 PUMP TEST OF THE LOWER
AQUIFER ZONE (10-7-86 to 10-17-86)

PROJECT No. PR86-006	DATE 11-26-86	REVISION 1

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.

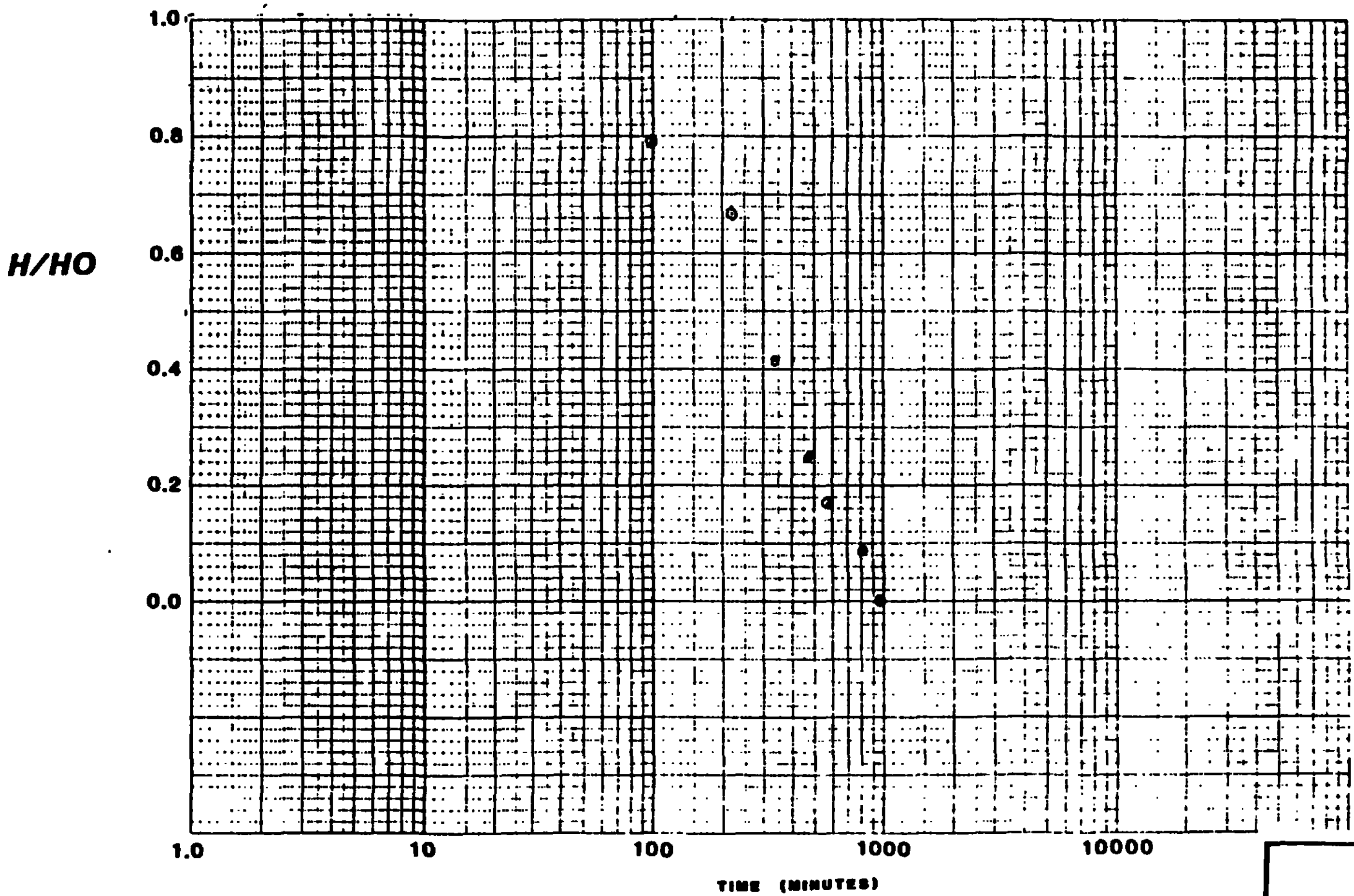


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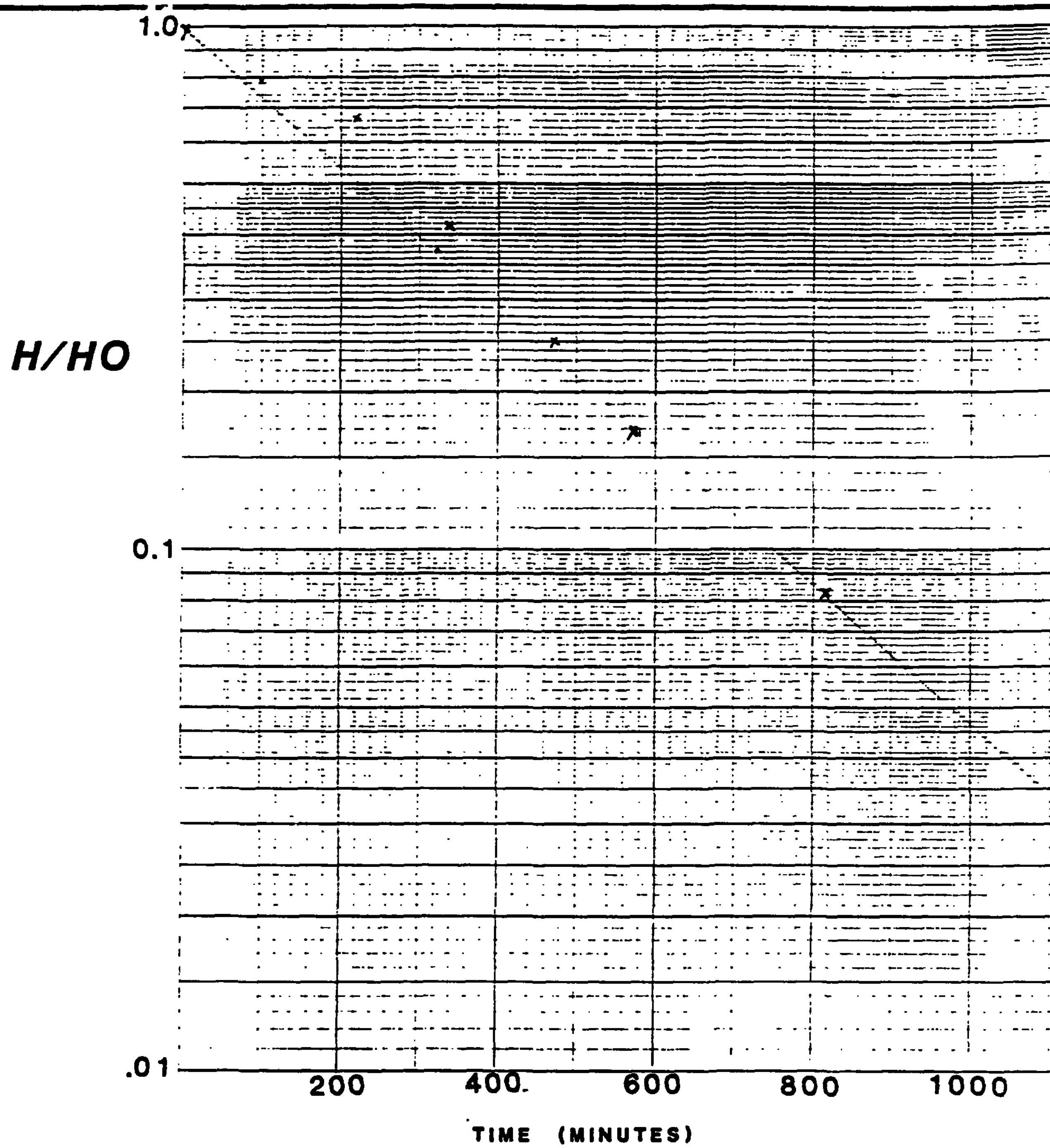
FIGURE 6-40

COOPER-PAPADOPOULOS PLOT

PUMPED WELL: PRECIPITATION LOADING
OBSERVATION WELL: P-10-2
DATE(S): ____________

PROJECT No.	DATE	REVISION

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

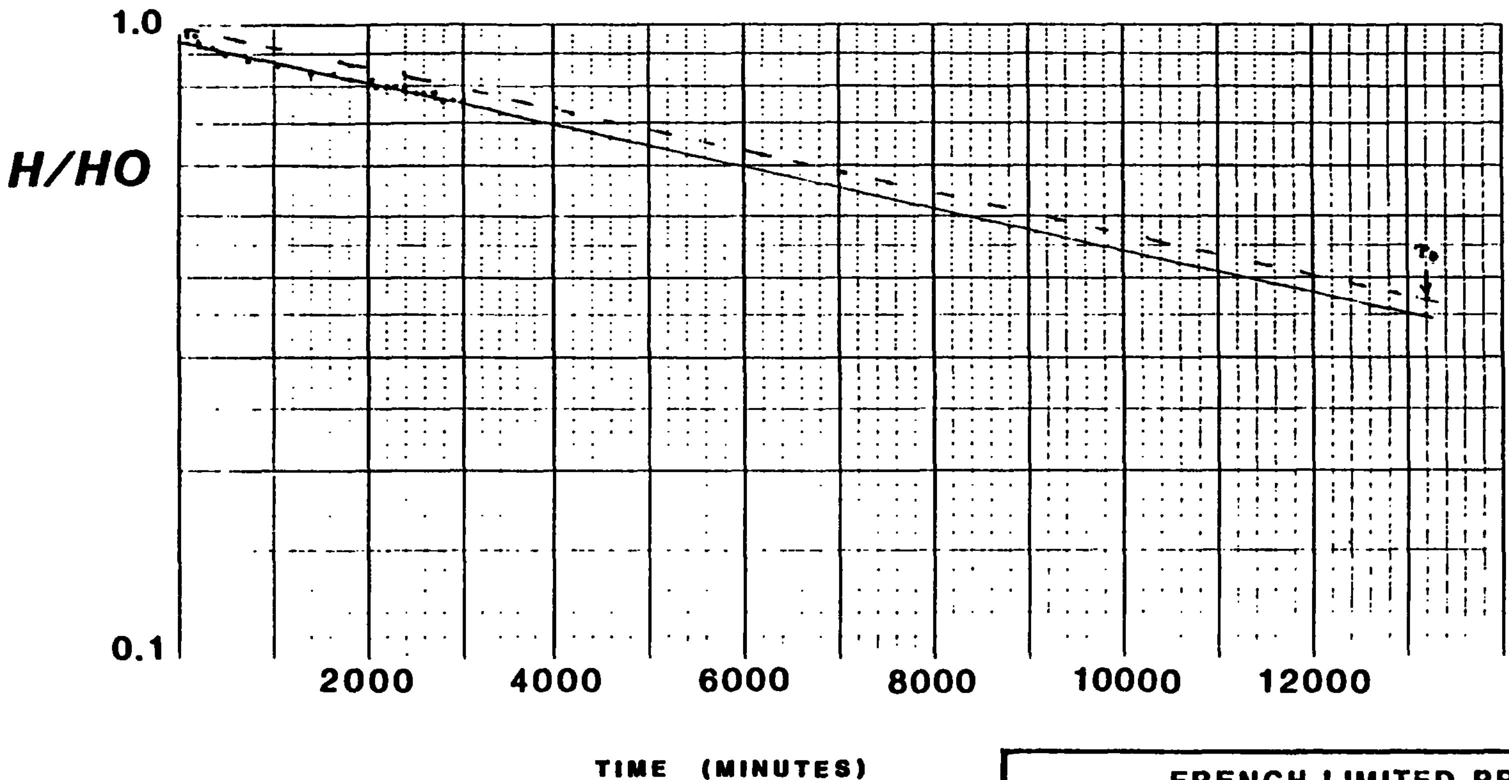
FIGURE 6-41

HVORSLEV PLOT

PUMPED WELL: PRECIPITATION LOADING
OBSERVATION WELL: P-10-2
DATE(S):

PROJECT No.	DATE	REVISION

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

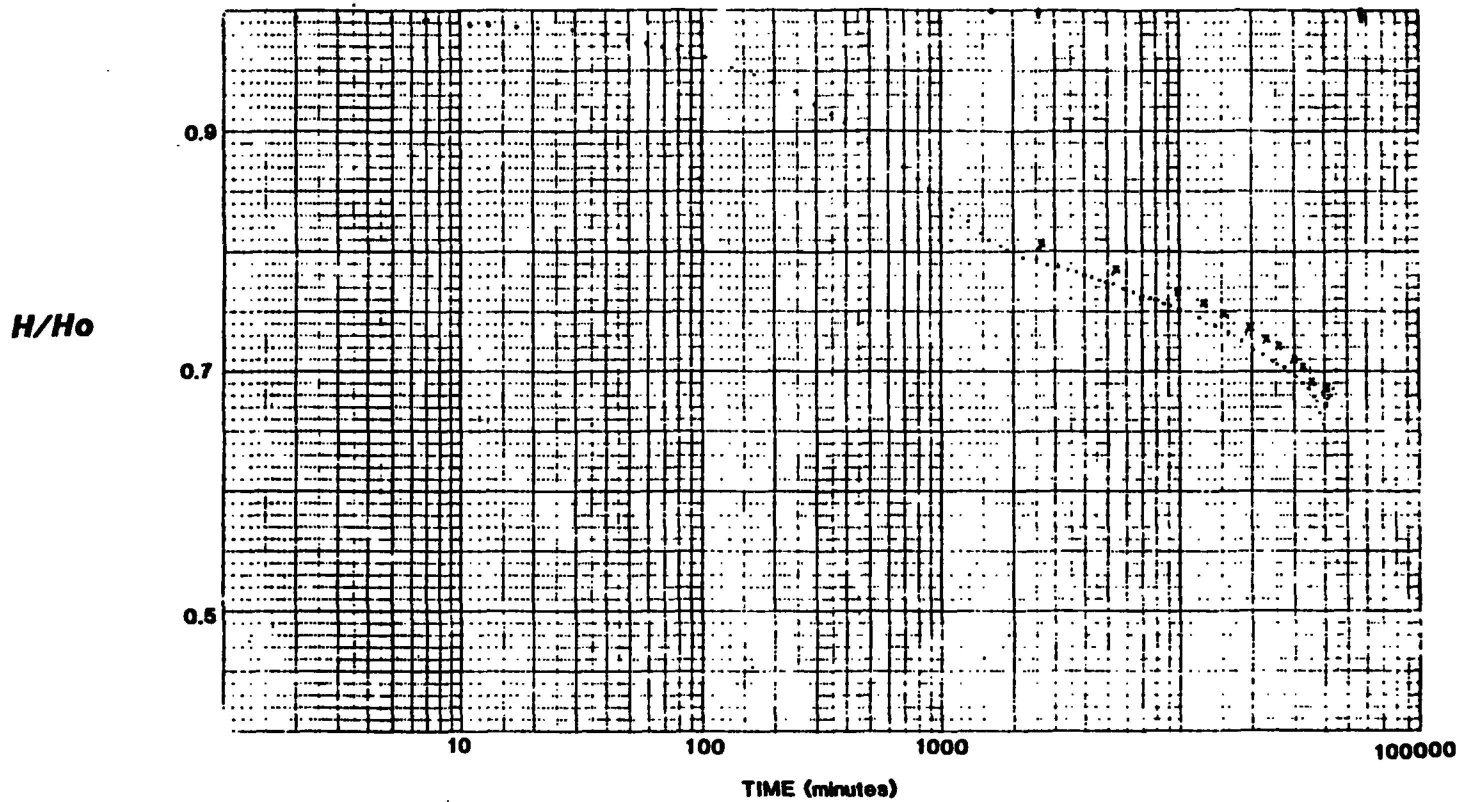
FIGURE 6-42

HVORSLEV PLOT

PUMPED WELL: PRECIPITATION LOADING
OBSERVATION WELL: P-10-4
DATE(S): ____________

PROJECT No.	DATE	REVISION

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



x SOUNDER MEASUREMENTS

. TRANSDUCER MEASUREMENTS

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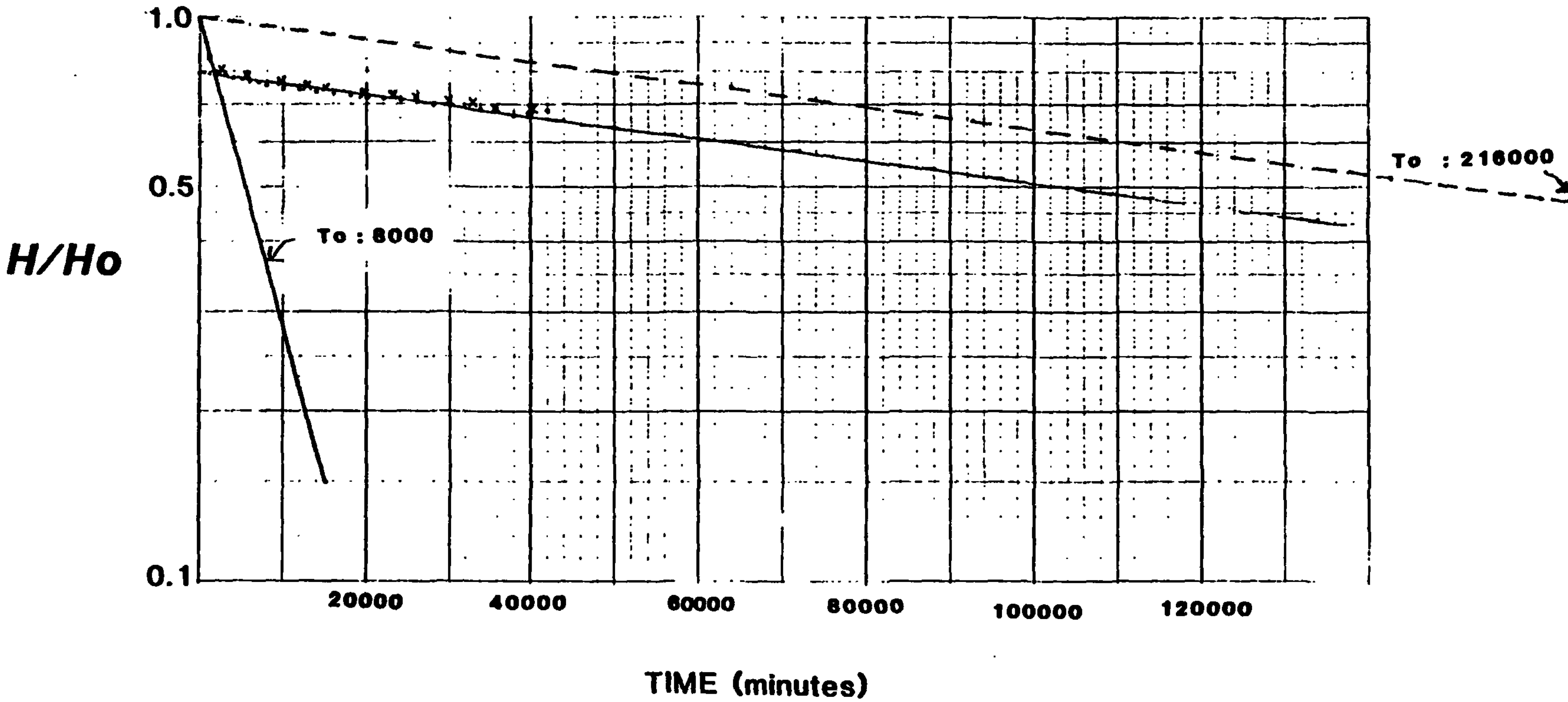
CROSBY, TEXAS

FIGURE 6-43
COOPER-PAPADOPULOS PLOT

PUMPED WELL: SLUG TEST WELL P-10-3
OBSERVATION WELL: P-10-3
DATE(S): 11/3 TO 12/3

PROJECT No.	DATE	REVISION

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.



FRENCH LIMITED PROJECT
CROSBY, TEXAS

FIGURE 6-45
HVORSLEV PLOT

PUMPED WELL: SLUG TEST WELL P-10-3
OBSERVATION WELL: P-10-3
DATE(S): 11/3 TO 12/3

PROJECT No.	DATE	REVISION

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.

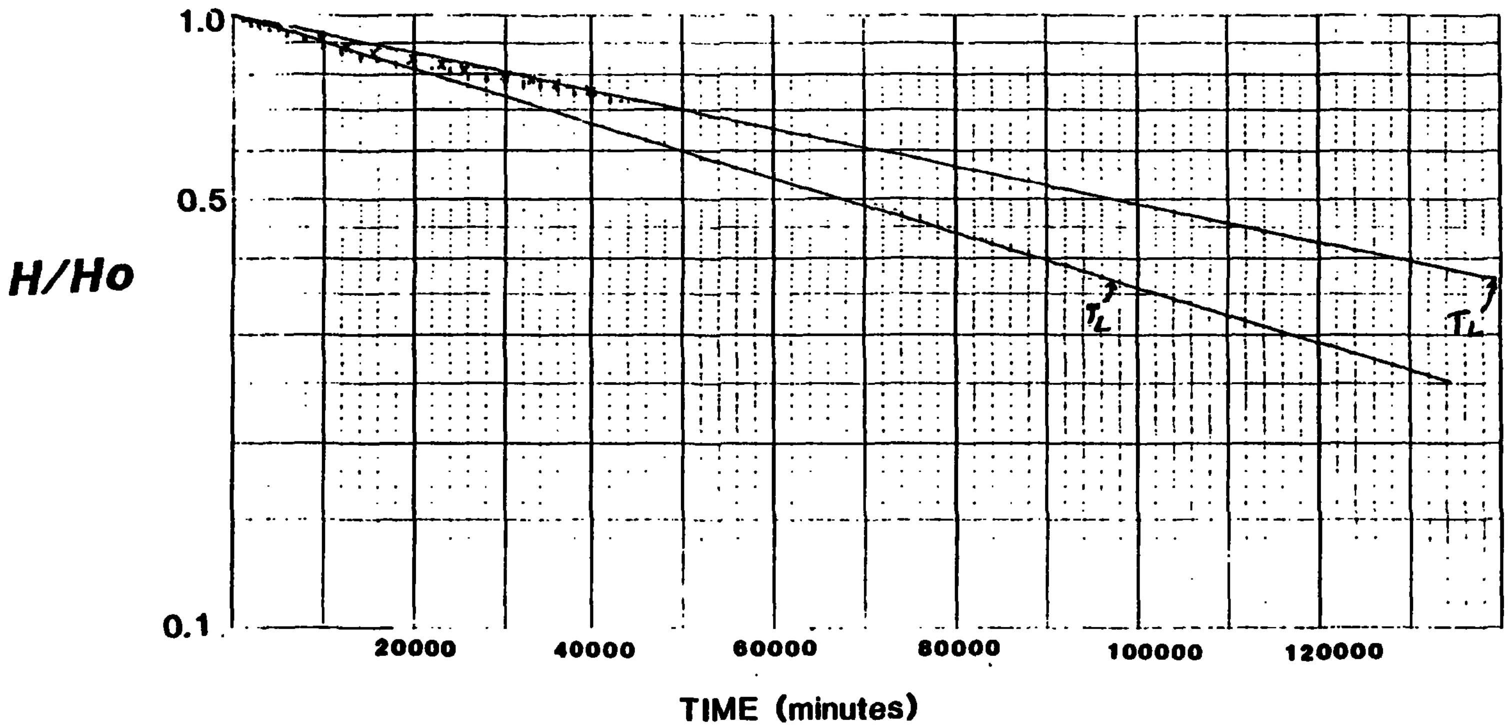


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FIGURE 6-46
HVORSLEV PLOT

PUMPED WELL: SLUG TEST WELL P-10-4
OBSERVATION WELL: P-10-4
DATE(S): 11/3 TO 12/3

PROJECT No.	DATE	REVISION

PREPARED BY: APPLIED HYDROLOGY ASSOCIATES, DENVER CO.

7.0 HYDROGEOLOGIC ASSESSMENT

7.1 UPPER ALLUVIAL ZONE CHARACTERIZATION

Geologic information from a number of drill holes and cone penetrometer holes indicates a high degree of vertical and lateral grain-size variation within the upper zone which is typical of alluvial deposits. Despite this variation, it is reasonable to treat the upper alluvial as a single hydrogeologic unit in the vicinity of the French Limited site. The unit is recharged directly by precipitation and from surface runoff and ponds.

Slightly higher water levels elevations have been noted in the lagoon compared with the adjacent water table in the upper alluvial zone. This indicates that the hydrologic communication between the lagoon and the adjacent geologic units is restricted by low permeability materials, probably sludges on the bottom of the lagoon. The lateral hydraulic gradient in the vicinity of the lagoon is about 0.002 to the south-southeast which is similar to the regional hydraulic gradient for this zone in this area. Recharge from the lagoon is therefore at a low enough rate that significant "mounding" of the water table is not apparent. Ground water flow in the upper alluvial deposits will tend to follow the path of least resistance (highest permeability) which usually approaches horizontal due to the bedded nature of the deposits. Low permeability clay and silt units within the zone tend to locally restrict vertical ground water movement. Nevertheless, there appears to be reasonably good vertical hydraulic communication within the upper alluvial zone in the vicinity of the French Limited Lagoon. This is suggested by the similarity of potentiometric levels within the upper alluvial zone and the rapid response of monitoring wells completed at the base of the zone to influences affecting the near-surface water table.

The vertical hydraulic communication in the upper alluvial zone at the REI-3 site is somewhat less than near the lagoon. This is indicated by evidence of confined conditions at the base of the zone and the identification of significant clay units within the zone. Hydrogeologic characteristics of the upper alluvial zone have been measured directly by field testing only at the REI-3 site. Lateral hydraulic conductivities for the sand units range from 6×10^{-4} to 1.2×10^{-3} cm/sec. (Section 6.1 and REI, 1986) Hydrogeologic characteristics for the sand units of the upper alluvial zone in the vicinity of the French Limited lagoon are probably similar to those at the REI-3 site based on similarity of grain size.

7.2 MIDDLE CLAYEY ZONE CHARACTERIZATION

The overall fine-grained nature of the middle clayey zone, the existence of consistent clay units within the zone and the large potentiometric drop across the zone all indicate that this zone forms an aquiclude separating the upper alluvial zone from the lower silty sand zone. A consistent stiff clay unit within the zone is believed to be particularly important in this respect.

The low vertical permeability of the zone is demonstrated by the pore pressure response of the geologic units below the stiff clay unit described in previous sections of this report. The blanket loadings imposed by precipitation events are reflected almost perfectly in pore pressure increases in the geologic units below the stiff clay. These pore pressure increases are maintained as long as the loading is imposed which is only possible if vertical drainage to relieve pore pressure is minimal. This observation is very important because it demonstrates that there are no significant high permeability conduits through the middle clayey unit that may act to relieve pressure from these lower units. Hydrologic bypasses of the middle clayey zone by natural features such as sand channels or major fracture zones is therefore highly unlikely.

Quantitative evaluation of the hydrologic characteristics of the middle clayey zone, specifically in the vicinity of the lagoon, have been evaluated from the response of the silt and clay piezometers to both naturally and artificially imposed stresses. Analysis of the drawdown response of the REI P-10-2 piezometer to pumping of the lower silty sand zone using the ratio method of Neuman and Witherspoon (1972) indicates a vertical hydraulic conductivity for the lower part of this zone of about 7 x 10^{-7} cm/sec. The lateral hydraulic conductivity of the silt zone in which the P-10-2 piezometer is completed was estimated from analysis of the piezometer response to precipitation loading at about 3 x 10^{-6} cm/sec.

The vertical hydraulic conductivity of the stiff clay unit could not be determined directly as no response was observed to pumping of the underlying lower silty sand unit. However, the lack of response after 10,300 minutes according to the Neuman and Witherspoon (1972) analysis indicates an average vertical hydraulic conductivity for the interval between the P-10-4 piezometer completed in the upper part of the stiff clay and the lower silty sand zone of less than 2.5 x 10^{-7} cm/sec. The horizontal hydraulic conductivity for the stiff clay has been estimated from the response of the clay piezometers to slug tests and to precipitation loading. Calculated values range from 10^{-6} to 10^{-8} cm/sec. The more reliable slug test results suggest a horizontal hydraulic conductivity between 10^{-7} and 10^{-8} cm/sec.

Comparison of hydraulic conductivity values of the stiff clay estimated from field tests and laboratory tests indicates field values are about two orders of magnitude higher. This is fairly typical as laboratory tests do not take into account secondary features such as slickensides which influence field conductivity values. The fact that this difference is apparent indicates that the field values are not significantly influenced by drilling effects during well completion. If smearing of fractures caused a significant "skin" effect then field values would probably be closer to laboratory values. Vertical hydraulic conductivities rarely exceed horizontal conductivities but may be similar if vertical slickensides are a predominant influence on fluid flow. Consequently, the maximum vertical conductivity of the stiff clay unit is thought to be about 10^{-7} cm/sec.

7.3 LOWER SILTY SAND ZONE CHARACTERIZATION

The lower silty sand zone has been characterized as a confined aquifer unit having variable geologic and hydrogeologic characteristics in the area investigated. The measured average hydraulic conductivity of the zone ranges from a high value of 4 x 10^{-3} cm/sec based on tests conducted on the REI 10-1 well, to a low of 1 x 10^{-3} cm/sec based on testing of the REI 3-4 well. Well yield in the REI 12-1 well indicates an average hydraulic conductivity within this range. The poor response of the REI-7 well to pumping of both the REI 3-4 and REI 10-1 wells indicates lower average hydraulic conductivities in the eastern section of the area investigated. Lateral flow probably predominates in the lower zone. The lateral potentiometric gradient is about 0.001 and is generally to the east.

7.4 CONTAMINANT MIGRATION ASSESSMENT

7.4.1 Upper Alluvial Zone

The high levels of contaminants in the upper alluvial zone ground water in the vicinity of the French Limited Lagoon is evidence of seepage from the lagoon. The lack of significant mounding of the water table near the lagoon suggests a low rate of seepage from the lagoon. However, given that contaminated water has been present in the lagoon for about 20 years, even a low rate of seepage would cause contamination of ground water in the upper alluvial zone adjacent to the lagoon.

Lateral contaminant migration within the upper alluvial zone will be primarily in the highest permeability units. The highest average hydraulic conductivity values measured in this zone is about 1.2 x 10^{-3} cm/sec. Individual sand or gravel units within the zone may have hydraulic conductivities an order of magnitude higher. Using an average hydraulic gradient of 0.002 and an assumed porosity of about 0.3, the rate of lateral ground water flow in the highest permeability units may be up to 80 ft/year. On this basis, over the past 20 years contaminants may have migrated up to 1600 feet from the lagoon. Field investigations have confirmed ground water contamination up to 1000 feet from the lagoon which is in good agreement with calculations.

Vertical contaminant migration in the upper alluvial zone is influenced primarily by the lowest permeability units within the zone. In the vicinity of the lagoon there does not appear to be any major clay units within the zone. Average vertical hydraulic conductivity in the zone is probably in the range of 10^{-4} to 10^{-5} cm/sec. The average vertical hydraulic gradient is approximately 0.02 based on estimated water table elevation and measured potentiometric elevation at the base of the zone. Assuming an average porosity of 0.3, a vertical ground water flow rate of between 0.7 and 7 ft/year is calculated. If conditions have remained essentially the same for about 20 years, and contaminants move at about the same rate as the ground water then the upper alluvial zone adjacent to the lagoon should contain contaminants to a depth of between 14 feet and the total depth of alluvial deposits which is 50 feet. Field observations indicate ground water contamination throughout the entire thickness of the upper alluvial zone and at the top of the middle clayey zone. The field observations therefore are in agreement with the higher range of calculated vertical flow rates in the upper alluvial zone.

7.4.2 Middle Clayey Zone

Groundwater flow in the middle clayey zone is primarily downward under the prevailing vertical hydraulic gradient of about 1.0. Maximum ground water flux through the zone based on maximum vertical hydraulic conductivities of 10-7 cm/sec is about 0.1 feet/year. The maximum rate of addition of contaminated groundwater to the lower zone that could develop in time is therefore about 0.01 gallons per year per square foot of affected area. Actual contaminant loading is dependent on contaminant concentrations within the ground water reaching the lower zone.

Actual ground water flow velocities through the middle clayey zone are dependent on whether intergranular or fracture flow predominates. Under intergranular flow, and assuming an intergranular porosity of about 0.3, maximum flow velocities would be in the order of 0.3 feet/year. Fracture flow velocities may be much higher due to the very much lower fracture porosities. In terms of contaminant migration, the processes of dispersion, adsorption, and diffusion tend to retard the rate of transport below ground water flow velocities. These processes operate very effectively in fracture flow situations so that contaminant migration tends to be closer to intergranular flow rates even if fracture flow predominates (Cherry et al, 1984, and Foster, 1975).

Field observations of contamination in the middle clayey zone indicate some traces in the upper few feet of the zone. This would be consistent with calculated intergranular flow rates in the middle clayey zone if contamination of the ground water immediately above the zone has existed for at least the past 10 years. At these rates, and if vertical hydraulic gradients remain about the same, it would take at least 230 years for contaminated ground water to move through the 70 feet thick middle clayey unit into the lower silty sand aquifer zone. The actual time for contaminated ground water to reach the lower zone may be an order of magnitude longer considering retardation influences and vertical hydraulic conductivities for the zone that are probably lower than the maximum values used in this calculation. Even if contaminated ground water does eventually reach the lower aquifer through natural leakage the quantity of contamination involved which is related to the ground water flux, is very low. Section 7.4.3. addresses the potential influence of contaminant flux on concentrations in the lower silty sand zone.

Based on the flow rate calculations presented in this section and observed contamination in the middle clayey zone which appears to support the calculations, it is clear that the contamination of lower zone groundwater observed in the GW-25 well samples did not occur through natural leakage. The most likely explanation for this contamination which considers all the available evidence is leakage through an artificial penetration. This is discussed in more detail in Section 7.4.3.

7.4.3 Lower Silty Sand Zone

The average hydraulic gradient in the lower zone is about 0.001 to the east. The average hydraulic conductivity for the zone has been calculated to range from 1×10^{-3} to 4×10^{-3} cm/sec. Based on these values, lateral groundwater flux through the zone from equation (5-1) is therefore calculated to range from 1.0 to 4.0 feet per year. Assuming an average thickness for the zone of about 20 feet total ground water flow per foot width ranges from 150 to 600 gallons per year.

The maximum leakage rate through the middle clayey zone under the prevailing vertical hydraulic gradients has been calculated in Section 7.4.2 to be in the order of 0.01 gallons per square foot per year. The length of the ground water flow path in the lower aquifer that could be potentially affected by leakage of contaminated groundwater through the middle clayey zone is about 1500 feet. This value is based on the east-west extent of contamination in the upper alluvial zone. The width of the flow path in the lower aquifer zone that could be potentially affected is presently about 1000 feet based on the north-south extent of ground water contamination in the upper alluvial zone. Therefore, a maximum leakage rate to the lower zone of approximately 15,000 gallons per year may occur within the area of potential contamination.

Ground water flow within the lower aquifer is calculated to be 150-600 gallons per year per foot width or 150,000 to 600,000 gallons per year across the 1000 foot wide potentially affected zone. This would indicate a dilution of 10:1 to 40:1 of any contaminants reaching the lower aquifer zone. Dispersion and other retarding influences would further lower contaminant concentrations downgradient from the area of influence. It must be emphasized that maximum leakage rates have been used in these calculations to be conservative. Leakage rates are likely to be as much as an order of magnitude lower.

The 1986 field program results strongly support the existence of a continuous low permeability zone, the middle clayey zone, which separates the lower aquifer zone from the contaminated upper alluvial aquifer zone. The probable leakage rates through the middle clayey zone calculated in Section 7.4.2 do not support the possibility of contamination of lower zone ground water by natural leakage. Bypass of the middle clayey zone via fractures or sand channels is not supported by the results of the field program.

The most likely explanation of groundwater contamination noted in samples from the GW-25 well is leakage through artificial penetrations. During drilling out of the GW-25 well it was observed that the annulus of the well did not have a good cement bond. It is possible that the organic contaminants in the upper alluvial zone reacted with the cement and drilling mud used to grout GW-25. During the drilling and well completion program of the 1986 field studies, it was observed that the contaminated water caused drilling muds to froth and made it difficult to develop a good wall cake. Thus it is possible that any grouted well presents an opportunity for very localized leakage of contaminated groundwater to the lower zone.

A study by Kurt and Johnson (1982) has measured hydraulic conductivities of neat cement grout seals surrounding thermoplastic well casings. Values ranging from 2.0×10^{-4} to 10^{-3} cm/sec were measured at low test pressure. It was concluded that the casing acted to increase the effective permeability since hydraulic conductivities were higher than previously measured values for well grout mixtures. Using a hydraulic conductivity of 10^{-3} cm/sec and a well annulus area of 0.2 $ft.^2$, a leakage rate of 4.2 gpd would be sustained under existing hydraulic gradients and steady state conditions. This level of leakage could easily account for the levels of contamination seen in the lower zone at the GW-25 location.

Given the reasonably high transmissivities in the lower aquifer zone, a leakage rate of up to 100 gallons per day can be sustained which would cause less than a 0.1 foot "mound" in the potentiometric level of the lower zone under steady state conditions. Similarly, given the relatively high transmissivity of the upper alluvial zone, a leakage rate of this magnitude would cause less than 0.1 feet of drawdown in this zone under steady state conditions. Based on these estimates it would appear that the leakage rate was low enough that it was not measurable in either the upper alluvial zone or the lower silty sand zone.

Thus, it appears that contamination observed in samples collected from the GW-25 well either reached the lower aquifer during drilling or via leakage associated with the grout sealed annular space. It also seems likely that any conventionally grouted well casing offers an opportunity for accelerated rates of contaminant migration to the lower silty sand unit. Even though the volumetric rate of contamination is quite low, it appears at the point of sampling. Consequently, we expect that contaminant concentrations may over time appear in the REI-10-1 well. The time that it takes for contamination to appear and the measured concentrations will depend on the hydraulic conductivity of the grout seal. In any event, we expect this hydraulic conductivity to be at least several orders of magnitude higher than the natural vertical hydraulic conductivity of the middle clayey zone.

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APPENDIX 1

July 10, 1986

Richard L. Sloan
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Dear Dick:

As requested, we have summarized the agreements reached with respect to the French Limited Remedial Investigation work plan on July 8, 1986. Several issues were not finally settled as noted but general agreement was reached regarding the course of action.

1. Well locations at REI-10 Deep Aquifer test site:

   Locations for all wells to be completed were staked on site. It was agreed that a well, REI-10-1, would be completed in the same unit as GW-25 about 65 feet south east of well GW-25. Two clay piezometers, P-10-3 and P-10-4, will be completed at different depths in the confining clay. These piezometers are to be located about 20 ft. from well REI-10-1. Finally it was agreed that 3 wells, REI-10-2, REI-10-3, and REI-10-4 will be completed in the alluvial aquifer above the confining clay. Well REI-10-2 is located about 20 feet south of well REI-10-1. Well REI-10-3 is located about 40 ft. north-east of well REI-10-1 near the location of well GW-6R which was previously abandoned. Well REI-10-4 is located about 65 feet north-west of well REI-10-1 near the location of well GW-25.

2. Well location at REI-3 well cluster site:

   A tentative location was selected for an additional well to be completed at the REI-3 well cluster location in the unconfined alluvium. It was agreed that this well would serve as a pumping well and would be located to the south of well REI-3-3 and if possible in line with well REI-3-3 and the piezometer, REI-3-3 (obs) completed in the same interval.

3. Location of Proposed REI-11 Well and REI-12 Well:

   The location of the REI-11 Well was selected about midway between REI-7 and the proposed well REI-10-1. This well will be completed in the deep aquifer below the confining clay in order better define potentiometric gradients within this unit. Well REI-12 was also planned to better define the potentiometric gradient within the deep aquifer. A suggestion was made to move the location of the proposed REI-12 well further north towards the Sykes CERCLA site so that it could be twinned with an existing shallow monitoring well. After examination of the alternative site it was agreed that the original planned location should be retained and that an additional shallow well be completed at this site. It was also agreed that Well REI-12 would be tested instead of Well GW-12 to determine deep aquifer properties and the degree of communication through the confining clay unit.

4. Tests on Clay Piezometers at the REI-10 Site:

It was agreed that single-well response tests will be conducted on the two clay piezometers to be completed as part of the testing program to be conducted at the REI-10 site. In addition core samples will be collected from the clay. Consolidation tests will be conducted on clay samples taken for use in interpretation of the vertical permeability of the clay from the deep well test. AHA has provided recommendations at the end of this letter.

5. Alluvial Remnant Assessment

It was agreed that single well response tests will be conducted on the seven piezometers installed in conjunction with the confirming soil borings. The method of response testing was discussed but no agreement was reached concerning the procedures to use. AHA has provided recommendations at the end of this letter.

RECOMMENDATIONS FOR WELL TESTING PROCEDURES

1. Single-Well Response Tests

Response tests on wells are performed by the rapid increase or decrease of the water level in the well and the measurement of the water level response back to equilibrium conditions. Equilibrium water level conditions must be attained prior to initiating the test. In wells completed in geologic units of reasonably high permeability the response will be relatively rapid and may require the use of a transducer system to obtain sufficient data within the short time frame to perform a meaningful analysis. These tests should be repeated if the total response times are in the order of five minutes or less. Response tests in low permeability units may involve water level recovery of several days so that manual measurements taken a few times daily would be adequate for analysis. Tests of the clay piezometers at the REI-10 site will probably encounter these conditions.

The rapid increase or decrease of water level in the well may be achieved by a number of methods. The most common technique is the addition and/or removal of a weighted "slug" of known volume which allows the calculation of the instantaneous rise or fall of the water level in the well if the internal diameter of the well casing is accurately known. Addition of a known amount of water to a well-bore of known internal diameter is also a common technique but has the disadvantage of not causing an instantaneous rise in the water level and introduction of water to the well may complicate interpretation of any future water quality samples. At the French Limited site the shallow water levels which will be encountered in most of the wells to be tested would limit the water level rise that can be applied.

An alternative method of performing these tests is to cause a water level decline in the well by sealing and pressurizing the well casing using compressed air or nitrogen. Pressurization need only be a few pounds per square inch to achieve an adequate head differential. An accurate pressure gauge on the well-head will allow the head differential to be measured. After equilibrium of the water level in the well, the gas pressure may be released almost instantaneously and the recovery of the well monitored. This method is preferred as it allows a much larger stress to be applied to the well than either of the other methods and does not involve the introduction of water to the well.

2. Analysis of Unconfined Alluvial Aquifer Pump Tests.

If possible, a pressure transducer system should be used to record water levels in the observation wells so the non-steady state analysis techniques can be applied and the time at which boundary effects are encountered is recorded.

3. Analysis of Deep Aquifer Pump Test

It is our understanding that a pressure transducer/data logger system will be used to record water levels in the observation wells and clay piezometers during the test. This will allow a detailed record of water level variations to be maintained using minimal manpower. Transducer measurements will be verified periodically using standard water level sounders. Pumping rate during the test should be maintained within a range of +/- 0.1 gpm. An automatic flow control valve may be used to compensate for pumping rate fluctuations caused by variation in water level in the pumped well, variation in electrical supply to the submersible pump and other influences.

The Neuman and Witherspoon analysis for determining characteristics of the confining layer is the most appropriate analytical technique presently available but does require that test conditions such as pumping rate be maintained reasonably constant as indicated above. If suitably constant conditions cannot be maintained then numerical techniques may be required for analysis. In discussions with Neuman he has indicated that the only difficulty in applying the analysis technique at the French Limited site is if head fluctuations in the deep aquifer could also occur during the test as a result of other influences. AHA recommends monitoring all the wells during the 24 hour period preceding the test to insure that equilibrium conditions exist in the aquifers and intervening clay unit prior to the test and that any influences such as pumping within the deep aquifer are sufficiently remote that they are not seen at the REI-10 test site. It is particularly important to ensure that the clay piezometer water levels are at equilibrium as this may take many days to achieve after completion of the installations.

If you have any questions regarding the documentation of field discussions and/or recommendations presented in this letter, please contact us.

Sincerely Yours,

Arthur P. O'Hayre

Michael J. Day

cc: William E. Jacobs, REI
Don C. Porter, EPA

REVIEW OF

FRENCH LIMITED SITE

REMEDIAL INVESTIGATION REPORT

Prepared by

Applied Hydrology Associates

Prepared for

ARCO Chemicals Company

and

The French Limited Task Group

June 5, 1986

INTRODUCTION

The French Limited Site, an abandoned waste pit on 15 acres south of State Highway 90 in Crosby, Texas, has been designated for Remedial Investigation/Feasibility Study (RI/FS) under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). In December, 1982, the Texas Dept. of Water Resources, under a cooperative agreement with EPA, contracted to initiate a Remedial Investigation(RI). The field investigations were conducted and an initial RI report was completed by Lockwood, Andrews and Newman (LAN) in January, 1984. The French Limited Task Group was formed in late 1983 by potentially responsible parties to determine the most reasonable and environmentally acceptable remedial actions to be taken at the site. The Task Group contracted with Resource Engineering, Inc.(REI) to provide technical consulting services in support of the French Limited remedial investigations. A draft report documenting the additional site investigations developed by REI was issued by the Task Group in May, 1984. In April, 1985 upon EPA approval of a work plan, the French Limited Task Group entered into an Administrative Order to complete the RI investigations.

EPA generated extensive technical comments for both the draft and final RI reports submitted by the Task Group. The most critical and comprehensive issues raised by EPA involve the approaches and techniques for interpretation of geologic and hydrologic data. In order to resolve these issues ARCO Chemicals Company has authorized Applied Hydrology Associates, Inc (AHA) to prepare this independent review of the French Limited Site Final Remedial Investigation Report and associated EPA comments. The purpose of this review is to determine whether EPA has raised valid concerns about the analyses and interpretations made by REI in the RI report and to recommend alternative studies or interpretations that will help resolve EPA's concerns and facilitate evaluation of remedial action plans. The organization of this review follows Section III. EXPLANATORY COMMENTS from EPA's May 12, 1986 Comments on the April 1986, French Limited Remedial Investigation Report. This organization was selected because the EXPLANATORY COMMENTS provide EPA's major concerns with analyses and interpretation of geologic and hydrologic data.

REVIEW OF REMEDIAL INVESTIGATION REPORT AND ASSOCIATED EPA COMMENTS

1.0 Geology

EPA has questioned the interpretation of the contact between the Alluvium and the Beaumont based some of the boring logs (eg. GW-02 and B-11, Figure 11-1). Apparently, EPA believes that the red brown clay and underlying sandy silt identified in GW-02 and the red clay identified in B-11 are units in the Beaumont Formation. The boring log for GW-02 indicates that EPA's interpretation may be correct. The stiff red brown clay encountered at a depth of 36 ft below surface in GW-02 was identified as blocky in structure with slickensides -- a characteristic of the Beaumont. The red clay starting at a depth of 30 ft. below the surface in B-11 was identified in the boring log as a stiff red brown clay with silty sand lenses. Perhaps this too is part of the Beaumont. If the contact is modified to correspond with EPA's interpretation, it suggests a narrower river channel associated with the French Limited alluvium. It lends support to the interpretation of an erosional remnant (of the Beaumont) between the French Limited alluvium and the Riverdale alluvium. Thus GW-02 may be completed in the Beaumont but it is by no means representative of the Beaumont. It is representative of a unit of the Beaumont that has been eroded from much of the site.

EPA has also questioned the existence of both the parallel alluvial channels and the "clay ridge" depicted on Figures 11-1 and 11-2. EPA has a valid point that the geologic information provided from borings is insufficient to conclude that there are parallel channels and a locally extensive "clay ridge" as depicted in Figure 11-2. An understanding of river hydraulics and alluvial deposition processes together with existing bore hole logs lends credence to the concept of an erosional remnant separating the French Limited alluvium from the Riverdale alluvium. Potentiometric data from shallow wells in the area also support the presence of a locally extensive zone with lower permeabilities separating the French Limited and Riverdale alluvial zones. The potentiometric map in the LAN report shows the steepening of the potentiometric surface in the vicinity of the clay ridge identified by REI. The higher gradient in this location is most logically explained by the occurrence of a zone of lower permeability.

Additional field work to support the alluvial geology interpretations in the RI may not be necessary. It would appear that EPA's questions may have been generated in response to the manner of presentation rather than limitations or deficiencies in the geologic information. Although EPA fails to provide the basis for their concerns with the interpretations of the alluvial geology, it is likely that their primary concerns focus on the interpretations about the rate and direction of contaminant migration in the alluvial aquifer. In the RI report the geologic model is presented as a "fact" or starting point for the development of the potentiometric surface, flow directions and flow rates in the French Limited alluvium. As the geologic model is not fully supported by the existing geologic data, it is to be expected that EPA would question or attack the assumed model.

AHA recommends developing the potentiometric surface and contaminant concentration information for the alluvial aquifer and then interpreting how this information fits in with reasonable geologic models of the alluvium (see further discussion in Sections 2.1 and 3.1 of this report). If the primary issue is the rate and direction of contaminant migration, then the geologic model simply serves to explain or interpret the observed hydrologic data and contaminant concentration levels in the alluvium. Thus confirmation of the geologic model with additional drilling data is not necessary.

Finally, EPA has questioned continuity of the 15 ft. clay layer identified in the Beaumont (question 32). They argue that data from 4 borings and 11 cone penetrometer tests cannot be extrapolated to a regional basis as implied in Section 5.3 of the RI. EPA insists that the RI address the possibility of downward movement of fluids and contaminants through interfingering of sands and silts in the Beaumont.

Since the geologic data represent only point samples in space, the continuity of the clay layer can never be "proven" by bore hole data alone. The existing bore hole and cone penetrometer data provide strong evidence for the occurrence of a continuous clay layer in the vicinity of the lagoon. Further drilling may not resolve this issue to EPA's satisfaction. The real issue is not whether there is a 15 foot thick continuous clay in the Beaumont beneath the site, but what is the natural magnitude of leakage from the alluvial aquifer through the Beaumont and the extent to which leakage could contaminate the deep aquifer.

It is in fact possible that a continuous clay, depending upon the extent of secondary permeability due to its structure, could have a higher rate of vertical leakage than a clay unit with interbedded sand and silt lenses. Even though the laboratory tests of the clay unit in the Beaumont indicated extremely low permeabilities, it is not valid to apply permeability estimates from laboratory analysis of core samples to field conditions. The permeability of the clay layer is likely to be an order of magnitude or more higher than laboratory measurements. This occurs as a result of secondary permeability due to the structure of the formation or fractures that are not included in the laboratory tests or that are disturbed by sampling.

The issue of leakage through the Beaumont is crucial to the remedial action evaluation. Further discussion of this issue is included in Section 2.2 of this report. Recommendations for resolving this issue are included in Section 3.2.

2.0 Hydrogeology

2.1 Upper Ground Water Zone

AHA agrees with EPA that all valid surface and groundwater data in the unconfined aquifers should be used to construct a groundwater map. This information can then be explained or interpreted in light of a reasonable geologic model of the site. It is not surprising that EPA has not accepted the interpretation of an alluvial aquifer at the French Limited Site that is hydraulically isolated from the surface water bodies and surrounding unconfined aquifers without conclusive evidence to support such an interpretation (see previous discussion in Section 1.0). Geologic units and water bodies in contact with the alluvium would be expected to exhibit some degree of hydrologic communication. The magnitude of communication needs to be qualified rather than attempting to show hydrologic isolation of the alluvium. The analysis developed in Figure 11-2 should be presented as a simplified model of the dominant regional potentiometric gradient in the alluvial aquifer and not as a groundwater contour map. Recommendations for developing a groundwater contour map for the unconfined aquifers are provided in Section 3.1.

AHA's analysis of the information presented in the RI indicates that the proposed geologic model and estimated regional potentiometric gradient represent a reasonable interpretation. Nevertheless, the geologic units in the model should not be shown as hydraulically separated without the supporting data.

In order to estimate the rate and direction of contaminant migration in the alluvial aquifer, it may be beneficial to make some simplifying assumptions based on the geologic model. This is an accepted practice, provided that the estimates developed from the model are supported by observed data and the simplifying assumptions are not presented as facts (see Section 2.3 for further discussion). The analysis in the RI that led to the development of Figure 11-2 was an effort to assess the dominant rate and direction for groundwater movement in the French Limited alluvium based on simplifying assumptions and abstractions and should not be construed as a complete hydrologic representation of the upper aquifer at the site.

2.2 Pumping Test Analysis

2.2.1 Unconfined Well (REI 3-3) Test

A representative value for the transmissivity of the unconfined portion of the French Limited alluvial zone is important as it directly effects the calculated rate of contaminant movement in this zone. AHA agrees with EPA's comment that the steady-state Theim-Forchheimer analysis method employed in the RI is not the most appropriate method for evaluating the REI 3-3 test. The following reasons explain why the method is not appropriate:

1) The method is only valid for radial steady-state flow to the pumping well. Recharge effects from the adjacent sand pit invalidates the radial flow concept.

2) The apparent stabilization of water levels in the 3-3 observation well may be indicating the onset of "delayed yield" effects that would be expected in an unconfined situation. If this is the case then true equilibrium conditions required for the analysis technique are not in effect.

3) The water level fluctuation in the pumped well suggests that the pumping rate may have dropped slightly in the later parts of the test. Unfortunately, there is no record of pumping rate measurements or how a constant rate was maintained. Given the low pumping rate it is apparent that even minor fluctuations in the pumping rate in the order of 0.1 gpm will have a significant effect on water level response. The apparent stabilization in water level in the observation well may also be a response to a slight drop in pumping rate. Again, true equilibrium conditions for use of the steady-state method may not have been achieved.

The EPA comments on the use of the Theim-Forchheimer analysis dwell mainly on the validity of the method using data from the pumped well and one observation well. Their contention that two observation wells are required is not strictly true. While two observation wells render the method more reliable, the pumped well may be used as one of the observation wells provided that well-loss effects at the pumped well are not appreciable. Given the low pumping rate during the test and relatively small drawdown in the pumped well it is likely that well-loss effects are minimal. The radius of the gravel-packed interval in the pumped well is generally used as the "r" factor in the form of the equation referenced by the EPA. The reference from "Ground Water and Wells" that states that the method is only valid if permeability is previously determined by other techniques is applicable if the equation is being used to predict well yield. In this case the well yield is known so that permeability may be calculated from the equation.

AHA recommends that the test be re-evaluated using a more appropriate non-steady state method. The short duration of the test will not allow a complete analysis of the unconfined characteristics of the zone as "delayed yield" effects may only have started to become apparent when the test was terminated. The early time data from the test may yield a reasonably valid estimate of the transmissivity of the zone but not an accurate estimate of the storage coefficient (specific yield). This is not a significant drawback, however, as representative values for the permeability and porosity of the zone are the major requirements for predicting groundwater flow rates. Porosity of the zone has been estimated from sieve analysis which is reasonably accurate. The specific yield of unconfined aquifers is usually similar to the average porosity value.

2.2.2 Aquifer Recharge

The drawdown and recovery data from a pumped well must be interpreted with caution due to a number of factors which cause deviations from the idealized conditions assumed in the formulation of analytical methods. One of the often overlooked factors which may influence pumped well data is well-bore storage. Well-bore storage effects have been documented to have significant influence on early time drawdown and recovery data in pumped wells, particularly in low permeability formations when low pumping rates are used (Schafer, 1978). A copy of this paper is included with this report.

The rate of drawdown and recovery in pumped well during periods influenced by well-bore storage are much higher than under the assumptions of the standard non-steady state analytical techniques used in the RI and by EPA. Well-bore storage effects cause a relatively steeper slope in the early-time drawdown and recovery semi-log plots. Use of the early-time data thus leads to underestimations of transmissivity values and possible misinterpretation of the later, flatter slope on the semi-log plot as being caused by recharge or leakage effects. Observation well data may also be influenced by well-bore storage effects but generally these effects are minimal in comparison with the pumped well. Consequently, a well test conducted with an observation well is required to adequately assess the hydrologic characteristics of the deep aquifer.

Examination of the well specifications and pumping rate used in the 3-4 well test using a method proposed by Schafer (1978) indicates that well-bore storage effects would be apparent in the pumped well during the initial 60 minutes of both the drawdown and recovery periods of the test.

EPA's suggestion of "recharge" to the deep aquifer during the 3-4 well test is based primarily on the observation of a significant decrease in the rate of drawdown after about 60 minutes of pumping and the fact that extrapolation of early-time recovery data indicates a return to equilibrium conditions significantly earlier than would be expected under non-recharge conditions. Both analyses use data from the early portions of the drawdown and recovery periods which are influenced by well-bore storage. Drawdown and recovery data during these periods should not be included in the analysis. The aquifer characteristics should be calculated using data collected after well-bore storage effects become negligible, represented by the later, flatter portion of the semi-log plot.

The drawdown data during the period following significant well-bore storage effects is rather erratic and it is not possible to determine aquifer characteristics or make any conclusive interpretations regarding possible "recharge" effects. Examination of the recovery plot presented by EPA indicates that the latter time data does show the expected flattening although recovery measurements were terminated a little too early for an accurate analysis of this portion of the test. It would appear that extrapolation of the later recovery data which is not influenced by well-bore storage may not indicate significant "recharge" effects.

The well-bore storage influence on pumped well data during the early-time portions of the test obscures the observation of recharge, leakage or boundary conditions that may have been encountered during this period. However, the potential of leakage from the French Limited alluvium during the test cannot be eliminated on the basis of the available data. Contamination of the deep aquifer indicates that communication exists, or has existed during the past 20 years, and artificial penetration of the overlying aquitard has been suggested as a possible cause. Consequently, leakage from the alluvium via artificial penetrations is conceivable.

In summary, the REI 3-4 well test was not designed in a manner that could adequately characterize the deep aquifer and quantify the effective hydrologic communication between the deep aquifer and the French Limited alluvial zones. Recommendations on how this may be accomplished during additional tests are given in section 3.2.

The analysis of drawdown and recovery data from future well testing may indicate the influence of "recharge" conditions. However, the use of the term "recharge" is misleading. Recharge in the context of pump test analysis refers to any process which results in a net increase in the amount of water available to the pumping well over that which would be derived from an ideal aquifer having the same characteristics as encountered in the early portions of the test. Consequently, "recharge" may actually be derived from the pumped aquifer itself if the hydrogeologic characteristics of the unit are not uniform. Given the relatively complex geology at the French Limited site it should be expected that drawdown responses may not follow the theoretical drawdowns predicted by analytical techniques that are based on fairly ideal conditions.

Recharge effects that may be indicated by drawdown and recovery data of future well tests in the deep aquifer may be explained by a number of causes and a thorough examination of the geologic framework is required to make the best interpretation as to which cause is most likely. There is considerable evidence to suggest that the deep aquifer is relatively isolated hydrologically from the overlying French Limited alluvial deposits at this location, primarily the 80 foot head difference between the two units. Leakage from the overlying aquifer is not the most likely source of recharge effects. Some of the other more likely explanations of recharge effects are as follows:

1) A higher transmissivity in the deep aquifer at a distance from the pumped well. This may be a result of a thickening of the unit or a higher average permeability due to variation in clay content or overall grainsize within the unit

2) Delayed yield of water stored in clayey zones within the pumped unit or from the overlying and underlying aquitards.

3) Stratification of the pumped aquifer with cross-flow from lower permeability units to higher permeability units as a head differential is developed between these units.

4) Leakage from underlying aquifers

All these processes are consistent with the geologic conditions at the site and should be considered in the design and analysis of future well tests in the deep aquifer. The recommended testing program presented in section 3.2 attempts to avoide these issues by directly measuring the response in the aquitard and overlying alluvium that occurs as a result of stress testing the deep aquifer.

The issue of sufficient aquifer stress has been raised by EPA. The 30% drawdown achieved during the REI 3-4 well test appears to be reasonable. Sufficient aquifer stress for the test also concerns the time over which the stress is imposed. AHA's preliminary calculations indicate that a 24 hour test is not sufficiently long to adequately determine the degree of communication between the deep aquifer and the overlying alluvium. Recommendations in Section 3.2 address the design of a test that should determine the degree of communication between the two aquifers.

Water level fluctuations in the alluvial monitoring wells during the test have been explained by barometric effects. This statement should be supported by barometric readings if possible in light of EPA's concerns regarding possible communication. If barometric pressure fluctuations during the test were not measured then the water level fluctuations may be construed as evidence of communication with the deep aquifer.

2.3 Groundwater Flow Rates

AHA disagrees with EPA's contention that accurate estimates of groundwater flow rates are of primary importance to the identification of contaminant distribution in the groundwater regime. The identification of the contaminant distribution should be based on accurate sampling and analysis of contaminants in the groundwater system. Accurate estimates of groundwater flow rates and directions may be beneficial to explain the source of observed contamination or to predict future contamination.

EPA appears to be placing too much emphasis on accurate estimates of groundwater flow rates and direction. An accurate model of groundwater flow rates, velocities and direction of movement would require additional information on permeabilities, boundary conditions and recharge rates. The transient effects of flooding and recharge or discharge to and from the surface water bodies would be extremely difficult to identify and incorporate into a model of the hydraulics of the unconfined aquifer. Estimates derived from a steady state analysis using data at a particular point in time will depend on the transient recharge and discharge conditions at that time and may not reflect the dominant direction and rate of transport.

The analysis presented in Sections 11.5 and 11.6 of the RI was an effort to remove the effects of local recharge and discharge and to eliminate the complexities due to variable transmisivities for different geologic units in order to construct a dominant direction and rate of contaminant migration in the unconfined aquifer. This analysis was supported by observations of contaminant levels in the aquifer.

It seems likely that the transient effects of recharge and discharge and flooding would increase the dispersion of contaminants in the unconfined aquifer. For instance, flooding effects could result in low levels of contamination at locations not anticipated from groundwater analysis. Furthermore, this dispersion zone could overlap with the dispersion zones from other contaminant sources in the area.

Given that remedial action will be taken to prevent the continued migration of contaminants from the site, it would appear to be unproductive to dwell on accurately quantifying the rate, direction and velocity of groundwater movement in the unconfined aquifer. The approach taken in the RI is a reasonable effort to estimate the dominant rate and direction for contaminant migration although it may be necessary to update the analysis using regional gradients developed from the re-analysis of the potentiometric surface and using revised estimates for alluvial aquifer porosities and permeabilities (see Section 3.1 for recommendations concerning re-analysis of the hydrogeology of the upper groundwater zone). AHA concurs with EPA's comment that the basis for the porosity values used in the groundwater velocity calculations be documented. The estimate of 30%, derived from sieve analysis of zone 3-3 of the unconfined aquifer as presented in Table 6.7 of the RI may be the most appropriate estimate of porosity for the unconfined aquifer.

EPA requests that the Task Group consider the potential distribution of contaminants in the deep aquifer (Zone 3-4) based on a valid interpretation of pumping tests results. There is no basis to support EPA's suggestion that the recharge effects were observed in the deep well pump test as explained in detail in section 2.2. AHA agrees that the contamination observed in the deep aquifer ought to be explained by more conclusive evidence. We feel that the results of the additional studies suggested in Section 3.2 of this report should provide this type of data.

Further characterization of the deep aquifer is necessary to assess the feasibility of an on site closure. This information would be used to assess the impact of anticipated leakage through the Beaumont formation.

Contaminants would not be detected in the deep aquifer if the rate of leakage is sufficiently small relative to the rate of flow and dispersion in the deep aquifer. This evaluation would require information on anticipated leakage rates developed from the recommended studies in Section 3.2 and estimates of flow rates and approximate dispersion coefficients for the deep aquifer. Since, this assessment is likely to be completed under Feasibility Studies, detailed recommendations are not provided in this report.

3.0 Recommendations

3.1 Hydrogeology and Contaminant Migration in the Upper Groundwater Zone

The following recommendations were developed based on AHA's determination that EPA's concerns with the hydrogeologic analysis of the upper aquifer stems from the presentation of the analysis rather than from significant deficiencies in the data.

1) Further geologic analysis appears to be unwarrented. Complete determination of the geology of the site is not necessary for interpretation of the rate and direction of contaminant migration. A satisfactory interpretation of the rate and direction of contaminant migration in the upper aquifer has been developed in the RI. This analysis should be updated as described in Section 3.1.4 based on the results of the refinements in the hydrologic information as described below.

2) A groundwater contour map of the upper aquifer should be developed using information from all wells in the upper aquifer as well as water levels from surface water bodies in the area. This analysis will resolve many of the questions raised by EPA. Interpolation of groundwater contours can be developed with a basic understanding of the mechanics of groundwater flow in unconfined aquifers using the known water levels, the topography of the area and the geologic model of the upper aquifer. The geologic model is used to interpret the hydrologic data and the hydrologic data helps support the geologic model.

   Water levels collected on the same date or reasonably close to the same date should be used. The map should show the actual water levels at measured locations and the measurement date as well as the interpolated groundwater contours. If possible a separate analysis should be performed for a wet period and a dry period in order to provide a better feel for the transient effects associated with recharge and discharge in the area. The analysis should incorporate data from monitoring wells in the unconfined aquifer at the Sikes site. This information would allow a more accurate and defendable interpretation of the regional gradient controlling groundwater movement at the French Limited site. This information is needed for the revised assessment of the direction and rate of contaminant transport in the upper aquifer as described in item 4 below.

3) Pump test results from the upper aquifer recommended in Section 3.2 should be used with results from the REI 3-1, 3-2 and 3-3 tests and the slug tests to characterize the expected transmisivity of the alluvial aquifer and the likely range in this estimate. Porosity estimates should be developed based on sieve analysis of drill samples and comparison with literature values for similar aquifer materials. An expected porosity value for the upper aquifer should be developed along with a likely range for this estimate. This information can then be used to complete the revised contaminant transport analysis described in Section 3.1.4

4) A revised assessment of the rate and direction of groundwater transport should be developed following completion of the previous steps. If mounding or sinks associated with the surface water bodies are local, the effect of these features can be removed from the regional contour. The analysis should show zones where significant changes in transmisivity can be expected to occur. A regional gradient can be developed from the regional groundwater contour map to assess the dominant direction and rate of groundwater flow in the upper aquifer. The analysis should be performed using the upper and lower range of transmisivity estimates as well as the expected value. Velocity estimates can be determined from the flow estimate and an estimate of porosity of the aquifer. Again the range for these estimates as well as the expected value should be used to determine a range and expected value for groundwater velocity.

   It is important to recognize that groundwater velocity represents the expected rate of movement of a conservative(non-reacting) contaminant. Actual rates of contaminant transport may be reduced as a result of retardation by adsorption or chemical reactions. Furthermore, the velocity estimate represents an average for the aquifer. Individual molecules of water or contaminants will move faster and slower than the average. Thus, it is possible for contaminants to appear at low concentrations beyond the range predicted by the velocity calculation. These effects are referred to as mechanical dispersion.

3.2 Leakage through the Beaumont Formation

The quantification of the effective communication between the French Limited alluvium and the deep aquifer is critical to the evaluation of remedial action plans for the site. The geologic and hydrologic data collected at the site strongly support the existence of a continuous clay layer in the Beaumont Formation that probably has the characteristics to effectively isolate the two units. However, the existence of significant contamination in the deep aquifer indicates that communication with the overlying alluvium exists, or has existed during the past 20 years. The nature of this communication is not conclusively proven and the EPA has raised questions about the interpretation given in the RI report.

Three possibilities have been identified to explain the presence of contamination in the deep aquifer:

1) Communication through artificial penetrations in the clay layer particularly near well GW-25. This is the interpretation given by the Task Force and the evidence given in support of this includes:

   - The relatively discrete incidence of contamination in the deep aquifer

   - The suggestion of a groundwater "mound" in the vicinity of the GW-25 well

   - Drill hole data that indicate continuity of the clay layer

   - A head difference of about 80 feet between the alluvium and the deep aquifer that indicates very poor natural hydrologic communication

   - Extremely low laboratory permeability values of the clay.

2) Discontinuities, such as sand lenses, within the clay layer that would allow significant communication between the two aquifer units in relatively discrete areas. This has been suggested by the EPA with no supporting data. The head difference between the two aquifer units and the drill hole data do not support this interpretation. However, the possibility is difficult to disprove completely on the basis of these data.

3) Natural leakage through the continuous clay layer under the high vertical hydraulic gradients. This possibility has also been suggested by the EPA and would require that the natural vertical permeability of the clay layer several orders of magnitude higher than laboratory measurements indicate. Given that the clay is stiff and slickensided, higher field permeabilities for the clay layer are reasonably likely. The major argument against this possibility is that contamination was not found in the clay layer at three drill hole locations within the lagoon area. Again, the data cannot disprove the possibility completely as it is taken at discrete points.

While the existing data do indicate that artificial penetration is the most likely cause of the deep aquifer contamination, the proper evaluation of remedial action alternatives necessitates that the communication between the deep aquifer and the alluvium be determined more quantitatively. The emphesis of the recommended test program described below is to achieve this objective.

AHA recommends that a hydrologic test program be conducted in the vicinity of the GW-25 well that is specifically designed to identify the cause and quantify the degree of vertical communication between the deep aquifer and the alluvium. In addition, data from the tests will be used to better define the hydrologic characteristics of the deep aquifer, the shallow aquifer and the Beaumont aquitard at this site. This data will be used to assess the impacts of anticipated leakage of contaminants from the overlying alluvium. This location is recommended for the testing program because of the contamination in the deep aquifer which has been identified from samples taken from the GW-25 well. This infers that significant hydrologic communication with the alluvium may exist at this site and may be quantified by testing.

The recommended testing program consists primarily of conducting a relatively long-term well test in the deep aquifer and monitoring responses in the overlying clay layer and French Limited alluvium. Additional recommended testing at the site includes at least one and preferably two short-term tests in the lower unit of the alluvium and single-well response tests in the clay layer.

The recommended well layout to perform the program is shown in Figure 1 attached. The layout requires an additional deep aquifer well, three shallow wells completed in the lower part of the French Limited alluvium and two piezometers completed in the lower and central parts of the clay layer.

The new deep aquifer well will be utilized as the pumped well for the deep aquifer test. The well should be completed in a similar fashion to the 3-4 well and located about 15 feet from the GW-25 well. The existing GW-25 well will be used as a monitoring well for the deep aquifer test to allow a more definitive determination of deep aquifer characteristics than was possible at the 3-4 site.

The alluvial wells should be completed with 4 inch diameter casing in a similar fashion as the REI 3-3 well. The location of the alluvial wells in a triangular pattern at varying distances from the GW-25 well as shown in Figure 1 is designed to evaluate the contention that the well may be a conduit for contaminant migration to the deep aquifer. Static water level elevations in the three wells may reveal a hydraulic gradient towards the GW-25 well if significant leakage is taking place at this location. This process may also be revealed by the relative response of the three wells (if any) during the deep aquifer test. If the three wells show responses during the deep well test that are essentially the same then this would be indicative of a more uniform communication across the clay layer. During the deep aquifer test, it is recommended that packers should be set on one inch diameter pipe above the screened intervals of the alluvial wells so that water level responses will be more sensitive.

The clay piezometers should be completed using 1-2inch ID pipe through surface casing using similar techniques as recommended for the deep aquifer well. The lower sections of the piezometer holes should preferably be drilled using auger or air-rotary techniques. Screened and sand-packed intervals for the piezometers should be about 2 feet in length.

Initial calculations assuming various values for the hydrologic properties of the aquifers and the clay layer indicates that the deep aquifer test should be conducted for about six days. It is recognized that the available drawdown and limited permeability in the deep aquifer may not make this practical. The test should therefore be conducted as long as feasible. The alluvial wells and clay piezometers will be monitored during the deep aquifer test. Placing stress on the lower aquifer for several days should allow responses to be seen in the clay layer piezometers and possibly the overlying alluvial wells. It will be necessary to also monitor barometric pressure to evaluate possible barometric effects during the test.

As indicated above, it is recommended that a short-term (1-2 day) pump test be conducted on at least one of the shallow wells using the other two wells for observation. These tests will allow a more definitive determination of the alluvial hydrologic characteristics at this site. These values are necessary for complete evaluation of the deep well test results, particularly if responses are observed in the alluvial aquifer. In addition the test results will indicate whether the values derived from the tests at REI site 3 are representative of the area.

The two piezometers installed in the lower and central sections of the clay layer will serve a number of functions. Single-well response tests may be conducted on the piezometers to obtain direct information on the permeability of the clay unit. Comparison of field permeability values calculated from these tests with laboratory permeability measurements will indicate whether secondary features such as fractures or slickensides are significant with respect to the retardation characteristics of the clay layer.

The single-well response tests yield data on the lateral permeability of the unit rather than the vertical permeability. Monitoring of the piezometers during the deep well test will allow quantitative assessment of the vertical permeability of the clay layer. If communication exists between the two aquifers via the GW-25 well casing annulus or sand lenses then responses in the clay layer will be minimal and will probably be less than responses in the overlying alluvial monitoring wells. Significant leakage from the clay layer would be indicated by responses in the lower clay piezometer and possibly the central clay piezometer. An estimate of the vertical permeability in the clay layer may be made using the piezometer response data and accepted analytical techniques. It must be noted that the anticipated low permeability may result in a very slow recovery of water levels in the piezometers following completion and response testing. Allowance should be made for a sufficient recovery period so that equilibrium conditions occur prior to the deep aquifer test. The recovery period could be as long as several weeks and should be monitored by periodic level measurements.

Water quality samples taken from the piezometers may also yield direct evidence of any movement of contaminants through the clay layer as opposed to movement via artificial penetrations or sand lenses in the vicinity of the GW-25 location. Of course, extreme care must be taken during the installation of the deep well and the clay piezometers to insure that contamination does not occur as a result of drilling and well completion. Casing should be set and grouted through the upper aquifer and into the Beaumont clay unit. After the casing is set and before drilling into or through the clay, the drill stem should be decontaminated. Bentonite should be placed above the piezometers to insure that leakage does not occur down the annular space.

It is believed that the recommended testing program should resolve many of the conflicting interpretations that have been suggested regarding the nature and extent of communication between the deep aquifer and the overlying alluvium. If this can be effectively done then the feasibility of remedial actions for the site such as on site closure may be properly evaluated.

APPENDIX 2

DRILLING AND WELL COMPLETIONS

DEEP WELL COMPLETIONS

All of the "deep aquifer" wells, REI-10-1, REI-12-1 and REI-11, were drilled to a reddish brown or blue and reddish brown mottled silty clay layer considered to be the upper Beaumont Formation. Surface casing was set and grouted in place with a tremmie pipe. The grouting of surface casing at well REI-10-1 may not have been complete because of sloughing of gravels and cuttings resulting from the poor drilling conditions.

At each of the deep well locations the grout was allowed to set until the next day and drilling continued inside the surface casing to total depth. Drill holes were E-logged again and a screened interval was selected in what appeared to be higher permeability sand units bounded by silty clays. In well REI-10-1 a screened interval was installed from 123 to 148 in a predominantly silty sand to sandy unit bounded above by interbedded clays and sands and below by a blue green gravely clay. A sand pack was installed using a tremmie pipe to a depth of 2 feet above the screen. A two foot bentonite pellet seal was placed above the gravel pack and allowed to set for about an hour and then the annular space was grouted to the surface using a tremmie pipe. In well REI-11 the screened interval was placed from 137 to 152 feet in a silty sand unit bounded above and below by silty clays. A sand pack was installed suing a tremmie pipe to a depth of 2 feet above the screen. A fourteen foot bentonite pellet seal was placed above the gravel pack and allowed to set for about an hour. Then the annular space was grouted to the surface using a tremmie pipe. The screened interval for well REI-12-1 was placed from 114 feet to 151 feet in a silty sand to sandy silt unit bounded above and below by silty clays. The sand pack was installed using a tremmie pipe to a depth of about 4 feet above the screen and a 2.5 foot bentonite pellet seal placed above the sand pack. Once the bentonite was set, the annular space was grouted to the surface using a tremmie pipe.

With these completion techniques, it is unlikely that leakage will occur through the annular space. Even with the sloughing that occurred prior to grouting surface casing at REI-10-1, the grouting of inner casing to the surface has reduced the chance of bypass. Each of the deep wells were developed using a small submersible pump and allowed to recover prior to testing. Water levels were monitored prior to aquifer testing.

ALLUVIAL AQUIFER WELL COMPLETIONS

Three alluvial aquifer wells were installed at the REI-10 well cluster location. All three wells were completed to a total depth of about 48 feet, just above the reddish brown silty clays of the Beaumont Formation. A 13 to 20 foot screened section was installed in the bottom of each well and a sand pack was installed with a tremmie pipe up to a depth of 32 feet in well REI-10-2, 25 feet in well REI-10-3 and 33 feet in well REI-10-4. A 2 foot Bentonite pellet seal was placed on top of the sand pack and allowed to set for about an hour. Then the annular space was grouted to the surface. The open interval for each of these wells is predominantly fine sandy silts.

An alluvial aquifer well, REI-12-2, was also completed near the REI_12-1 well. The reddish Brown silty clay of the Beaumont was encountered at a depth of 54,feet below surface in well REI-12-1. Well REI-12-2 was drilled to a depth of 50 feet and a 15 foot screed section was placed in the predominantly silty dand unit from 34.5 to 49.5 feet. The annular space around the screen was sand packed using a tremmie pipe to a depth of 32 feet below surface. A 3 foot Bentonite pellet seal was placed on top ot the sand pack and allowed to set for about an hour. Then the annular space was grouted to the surface using a tremmie pipe.

Each of the shallow alluvial wells was developed using a small submersible pump prior to aquifer testing.

CLAY PIEZOMETER COMPLETIONS

The first clay piezometer, P-10-3, was drilled to a depth of 78 feet and logged. A shelby tube sample taken between a depth of 78 and 79.5 feet confirmed the presence of a heavy clay. A six inch pvc casing was installed and driven into the clay to a depth of 79.5 feet below ground surface and grouted in place using a tremmie pipe. The next day the clay was drilled to a depth of 84 feet using water and a 5.75 inch drill bit. Water in the hole was air lifted prior to installing the 2-inch pvc casing with a 2 ft. screened interval at the bottom of the hole. A volume of sand equivalent to about a 1.5 foot interval within the annular space was added. Tape measurements showed the sand to be at a depth of 79 feet below the surface. Thus it appeared that the clay may have expanded around the inner casing, causing the sand to bridge and not work its way down around the screened interval. As a consequence of this well completion problem, it is possible that the effective measurement increment for this piezometer could extend above the screened interval but no higher than the 79.5 foot depth where the outer casing appears.

A 3 foot bentonite pellet seal was placed on top of the sand pack and allowed to set while the grout was prepared. Then the annular space between the outer and inner casing was grouted to the surface. It is possible that the hydrostatic pressure of the grout may have forced the bridged sand down around the screened interval.

The other clay piezometer, P-10-4, was drilled to a depth of 78 feet. A shelby tube sample taken from the interval from 78 to 79.5 feet confirmed the presence of a heavy red clay. A six inch pvc casing was installed and driven into the clay to a depth of 80 feet below ground surface and grouted in place using a tremmie pipe. Next the clay was drilled to a depth of 82 feet using water and a 5.75 inch drill bit. Water in the hole was air lifted prior to installing the 2-inch pvc casing with a 2 ft. screened interval at the bottom of the hole. A volume of sand equivalent to about a 2 foot interval within the annular space was installed. A 2 foot bentonite pellet seas was placed on top of the sand pack and allowed to set while the grout was prepared. Then the annular space between the outer and inner casing was grouted to the surface using a tremmie pipe.

SILT PIEZOMETER

The drilling and logging the deep well, REI-10-1, revealed the lithology of the aquitard between the alluvial aquifer and the deep aquifer. A 34 foot interval consisting of interbedded sandy silts and clays was found to lie between the deep aquifer containing wells REI-10-1 and GW-25 and the thick heavy red clay unit containing the clay piezometers. AHA recommended that an additional piezometer be installed in the sandy silt immdeiately below the clay containing the clay piezometer to facilitate interpretation of the 7 day pump test of the deep aquifer.

It was felt that the additional piezometer could reveal a response during testing when perhaps the clay piezometers might not. Thus it would be possible to determine, the vertical permeability of the aquitard zone beneath the heavy clay. This estimate could then be compared to direct slug test measurements from the clay piezometers to narrow the range for the estimate of vertical permeability within the clay. Also, if the clay piezometers were to respond to the 7 day pump test, then the additional piezometer within the silt would allow for a direct determination of the vertical permeability of the heavy clay as well as the vertical permeability of the portions of the aquitard below the thick heavy clay unit.

The recommendation for the silt piezometer was discussed in a meeting with REI and the PRP representative and the decision was made to install the piezometer. The piezometer, P-10-2 was installed following the same proceedures as the two clay piezometers. The hole was drilled to 80 feet where a six inch pvc casing was installed and grouted in place using a tremmie pipe. Next the clay was drilled through with a 5.75 inch drill bit taking shelby tube samples every 2 feet. The shelby tube sample from the interval 90 to 91.5 feet revealed a dark green silt. A 1 -inch pvc casing with a 2 ft. screened interval was installed in the silt unit from 90 to 92 feet bounded above by the heavy clay unit. A volume of sand equivalent to about a 2 foot interval within the annular space was installed. A 2 foot bentonite pellet seas was placed on top of the sand pack and allowed to set while the grout was prepared. Then the annular space between the outer and inner casing was grouted to the surface using a tremmie pipe.

FRENCH LIMITED WASTE HAZARD SITE
JOB NO. 86.055

BASELINE CORPORATION

AUGUST 22, 1986

REVISED: SEPTEMBER 17, 1986

WELL SITE	EASTING	NORTHING	ELEVATION
TBM "C" (31)	11,363.16	10,056.05	14.64 (R.R. spike in centerline Gulf Pump Road Approx. 200 feet east of Maple St)
REI-10-1 (16)	12,102.42	10,108.71	12.8 (N.G.) 14.40 (top PVC @ bottom notch)
REI-10-2 (15)	12,109.56	10,084.34	11.9 (N.G.) 14.26 (top PVC @ bottom notch)
REI-10-3 (18)	12,047.35	10,141.01	13.8 (N.G.) 15.76 (top PVC @ bottom notch)
REI-10-4 (19)	12,120.28	10,138.40	14.4 (N.G.) 16.19 (top PVC @ bottom notch)
REI-3-5 (26)	12,598.86	9,495.79	10.0 (N.G.) 11.76 (top PVC @ bottom notch) 12.13 (top casing)
REI-#1 (12)	11,611.15	9,745.75	16.6 (N.G.) 18.75 (top PVC @ bottom notch)
REI-#2 (13)	11,633.32	10,094.03	10.3 (N.G.) 13.28 (top PVC @ bottom notch)
REI-#3 (14)	11,722.56	10,086.34	9.2 (N.G.) 11.69 (top PVC @ bottom notch)
REI-#4 (22)	11,943.57	10,094.28	9.5 (N.G.) 12.45 (top PVC @ bottom notch)
REI-12-1 (10)	10,739.44	10,715.92	10.5 (N.G.) 12.52 (top PVC @ bottom notch)

cont.

FRENCH LIMITED WASTE HAZARD SITE
JOB NO. 86.055
AUGUST 22, 1986
REVISED: SEPTEMBER 17, 1986

WELL SITE	EASTING	NORTHING	ELEVATION
REI-12-2 (11)	10,732.74	10,733.19	10.4 (N.G.) 12.26 (top PVC @ bottom notch)
REI-11 (25)	12,503.10	9,958.88	9.9 (N.G.) 11.79 (top PVC @ bottom notch)
P-10-2 (20)	12,116.62	10,123.96	13.8 (N.G.) 15.76 (top PVC @ paint mark)
P-10-3 (17)	12,094.04	10,127.11	13.4 (N.G.) 15.44 (top PVC @ bottom notch)
P-10-4 (21)	12,120.51	10,117.36	13.7 (N.G.) 15.22 (top PVC @ bottom notch)
GW-25 (30)	12,048.51	10,147.94	14.2 (N.G.) 15.94 (top PVC)
REI-7 (29)	13,111.27	10,020.53	10.6 (N.G.) 13.43 (top PVC)
REI-3-4 (27)	12,634.25	9,532.19	9.9 (N.G.) 14.05 (top PVC)

JWM:bgb
86.055bm

APPENDIX 3

RESULTS OF CONSOLIDATION TESTS ON CLAY SAMPLES

BORING NO: SAMPLE NO:

DEPTH, FT: 81-82

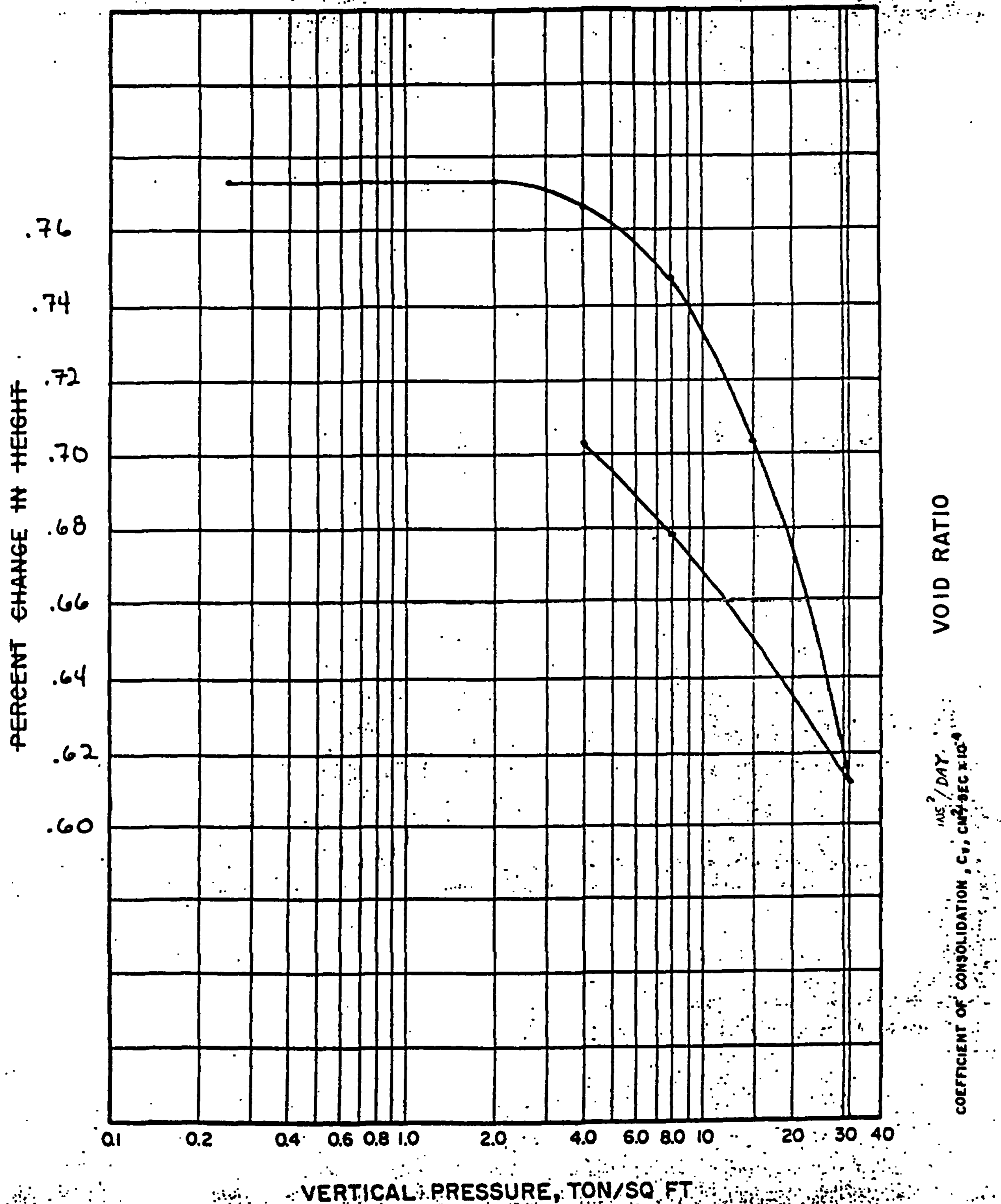
DESCRIPTION: Hard red clay with calcareous nodules, slickensided

UNIT DRY WEIGHT: 98.5 PCF

WATER CONTENT: 25.8 %

LIQUID LIMIT:

PLASTIC LIMIT:



CONSOLIDATION TEST RESULTS

FUGRO GULF, INC.
Consulting Engineers and Geologists

PLATE

CONSOLIDATION TEST

Date: 15AUG 85 **Project:** REI P10-4 **Job No.** ____

Boring No. ____ **Sample No.** ____ **Depth:** 81-82 **Ring No.** 2

Description: Hard red clay w/ calc. material slickensided

Liquid Limit ____

Plastic Limit ____

Test Specimen	Initial	Final
Wet wt sple + ring	146.39	145.42
Dry wt sple + ring	130.43	130.43
Wt of ring	71.27	71.27
Dry wt of sple		
Wt of water		
Water content, %	27.0	25.3

Trimmings, Can No. 400	
Wet wt + tare	57.19
Dry wt - tare	48.65
Tare wt	15.54
Dry wt	
Wt of water	
Water content, %	25.8

A. Specific Gravity 2.80 B. Volume of Sple 37.468 c.c. C. Initial Ht of Sple 0.750 in.

D. Final Ht of Sple ____ in. E. Unit Wet Wt 125.1 lb/ft^3 F. Unit Dry Wt 98.5 lb/ft^3

G. Ht of Solids $= \frac{\text{Final Dry Wt Sple}}{A} \times \frac{C}{B} =$ .4229 in. $\frac{1}{G} =$ ____

H. Initial Void Ratio: $= \frac{C - G}{G} =$ 0.7733

d = 1.97

Percent Saturation:

Before Test $= \frac{\text{Initial Wt Water}}{B - \frac{\text{Dry Wt Sple}}{A}} \times 100 =$ 97.7 %

After Test $= \frac{\text{Final Wt Water}}{B \times \frac{D}{C} - \frac{\text{Dry Wt Sple}}{A}} \times 100 =$ 101.0 %

Consolidometer No: ____ $^*P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change. in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v $in.^2/day$
.0000	0	.2500	—						
.0002	.25	—							
.0008	.5	—							
.0019	1	—							
.0035	2	—							
.0054	4	.2584	.0084	.0030			.766	6.0	6.594
.0073	8	.2686	.0186	.0113			.747	8.0	4.836
.0095	16	.2892	.0392	.0297			.703	14.0	2.452
.0123	32	.3276	.0776	.0653			.612	40.0	0.824
.0100	8	.3005	.0505	.0405			.678		
.0087	4	.2888	.0388	.0301			.702		

Tested By: ____
Computed By: ____
Checked By: ____

CONSOLIDATION TEST
DATA SHEET

Job No. ________ Boring No. P10-4 Depth 81-82 Consol. No. 2

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
QJN	15 Aug	1250	0	.2500	.25 Kg/cm²
			.1	.2506	
			.25	.2509	
			.5	.2510	
	add H_2O →		1	.2511	
			2	.2500	SWELL
		1253	0	.2500	.5 Kg/cm²
			.1	.2504	
			.25	.2504½	
			.5	.2504	
			1	.2503	
			2	.2501	SWELL
R.W.	15 Aug	1255	0	.2501	1.0 Kg/cm²
			.1	.2511	
			.25	.2512	
			.5	.2512½	
			1	.2513	
			2	.2512	
			4	.2511	SWELL
QJN	15 Aug	1300	0	.2511	2.0 Kg/cm²
			.1	.2525	
			.25	.2527	
			.5	.2528½	
			1	.2529½	
			2	.2530½	
			4	.2531	
			8	.2531	
			15	.2529½	SWELL

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
QJN	15 Aug 86	1320	0	.2529	4 Kg/cm²
			.1	.2551	
			.25	.2554	
			.5	.2556½	
			1	.2559	
			2	.2562	
			4	.2565	
			8	.2568	
			15	.2571	
			30	.2573½	
		1420	60	.2575½	
		1520	120	.2577	
		1720	240	.2578	
	16 Aug	0900	1120	.2580	
QJN	16 Aug	0905	0	.2580	8 Kg/cm²
			.1	.2610	
			.25	.2613½	
			.5	.2617½	
			1	.2623	
			2	.2629	
			4	.2636½	
			8	.2646	
			15	.2656	
			30	.2662½	
			60	.2678	
			120	.2687	
			240	[illegible]	
			480	.2693	
	17 Aug	0800	1380	.2698	
	17 Aug	0805	0	.2698	16 Kg/cm²
			.1	.2735	
			.25	.2741	
			.5	.2747½	
			1	.2755	
			2	.2763	
			4	.2775	
			8	.2791	
			15	.2810	
			30	.2837	
			60	.2862	
			120	.2880	
			240	.2892	
			480	.2900	
	18 Aug	0635		.2909	

CONSOLIDATION TEST

Date:________ Project:____________________ Job No.________

Boring No.________ Sample No.________ Depth:________ Ring No.________

Description:______________________________ Liquid Limit ________

______________________________ Plastic Limit ________

Test Specimen	Initial	Final
Wet wt sple + ring		
Dry wt sple + ring		
Wt of ring		
Dry wt of sple		
Wt of water		
Water content, %		

Trimmings, Can No.	
Wet wt + tare	
Dry wt - tare	
Tare wt	
Dry wt	
Wt of water	
Water content, %	

A. Specific Gravity________ B. Volume of Sple______ c.c. C. Initial Ht of Sple________ in.

D. Final Ht of Sple________ in. E. Unit Wet Wt______ lb/ft^3 F. Unit Dry Wt________ lb/ft^3

G. Ht of Solids $= \frac{\text{Final Dry Wt Sple}}{A} \times \frac{C}{B} =$ ________ in. $\frac{1}{G} =$ ________

H. Initial Void Ratio: $= \frac{C - G}{G} =$ ________

Percent Saturation:

Before Test $= \dfrac{\text{Initial Wt Water}}{B - \dfrac{\text{Dry Wt Sple}}{A}} \times 100 =$ ________ %

After Test $= \dfrac{\text{Final Wt Water}}{B \times \dfrac{D}{C} - \dfrac{\text{Dry Wt Sple}}{A}} \times 100 =$ ________ %

Consolidometer No: $^{*}P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v $in.^2/day$

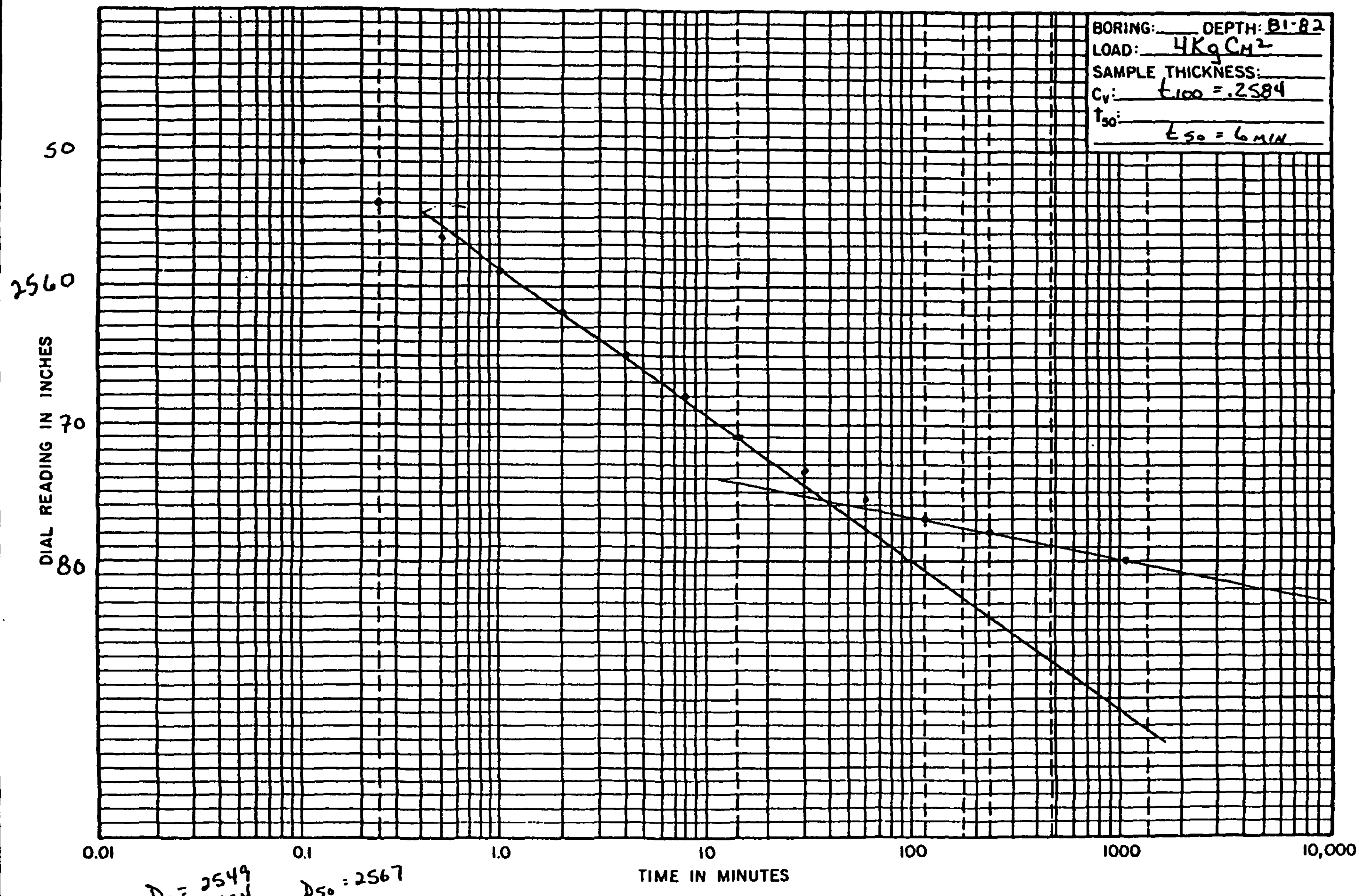
Tested By:________
Computed By:________
Checked By:________

CONSOLIDATION TEST
DATA SHEET

Job No. ______ Boring No. ______ Depth ______ Consol. No. ______

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
B.T.	19 Aug	0935	0	.2945	32 Kg/cm²
			.1	.2952	
			.25	.2958	
			.5	.2966	
			1	.2971	
			2	.2980	
			4	.2997½	
			8	.3021½	
			15	.3051	
			30	.3091	
			60	.3132	
		1135	120	.3162½	
			240	.3180	
		1645	430	.3191	
		0810		.3204	
	Rebound				
B.T.	20 Aug	0810	0	.3204	8 Kg/cm²
B.T.	21 Aug	0820	1450	.3005	
	Rebound				
	21 Aug	0835	0	.3005	4 Kg/cm²
	22 Aug	1130		.2888	

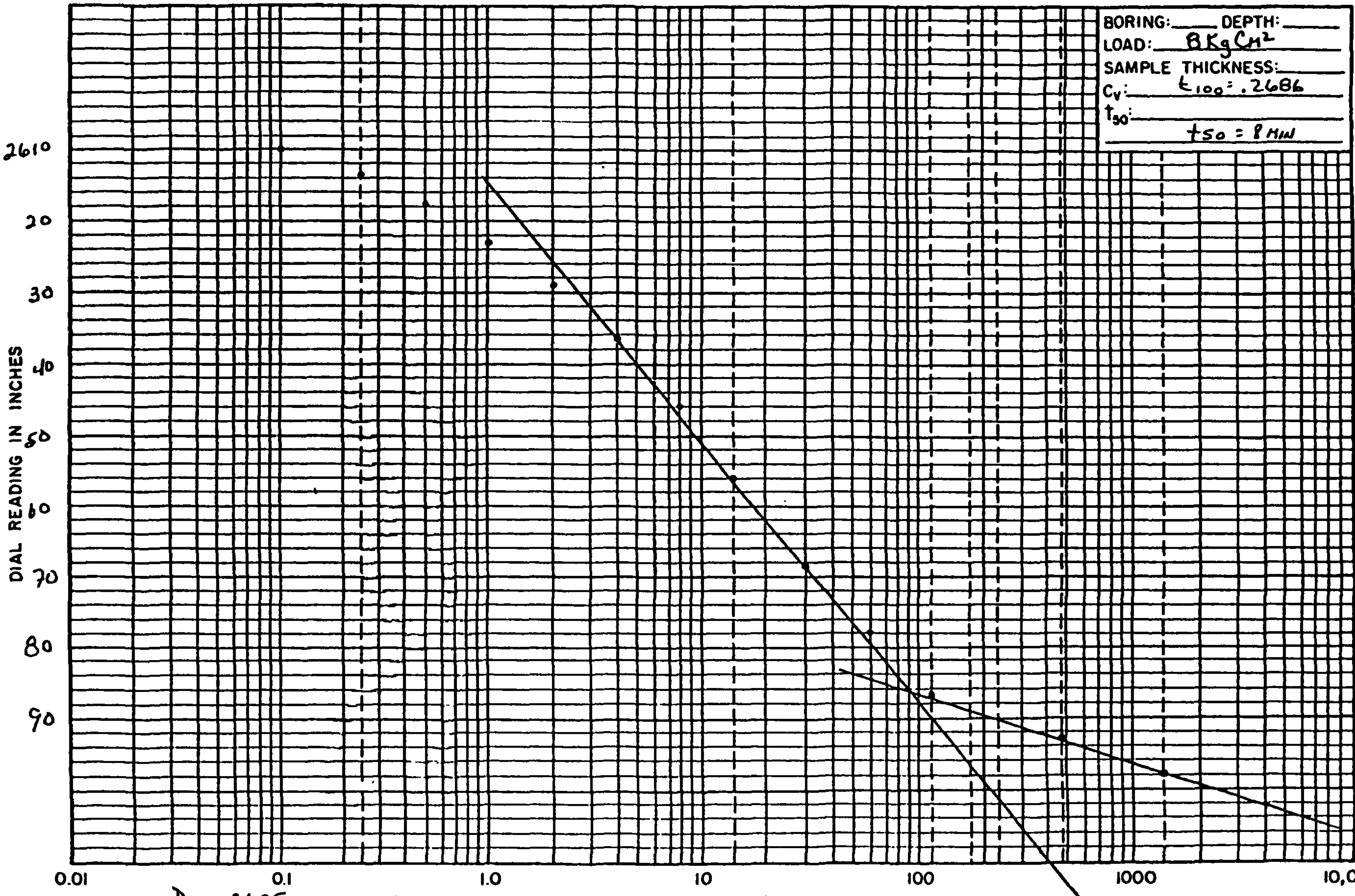
FUGRO GULF, INC.
Consulting Engineers and Geologists



CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists

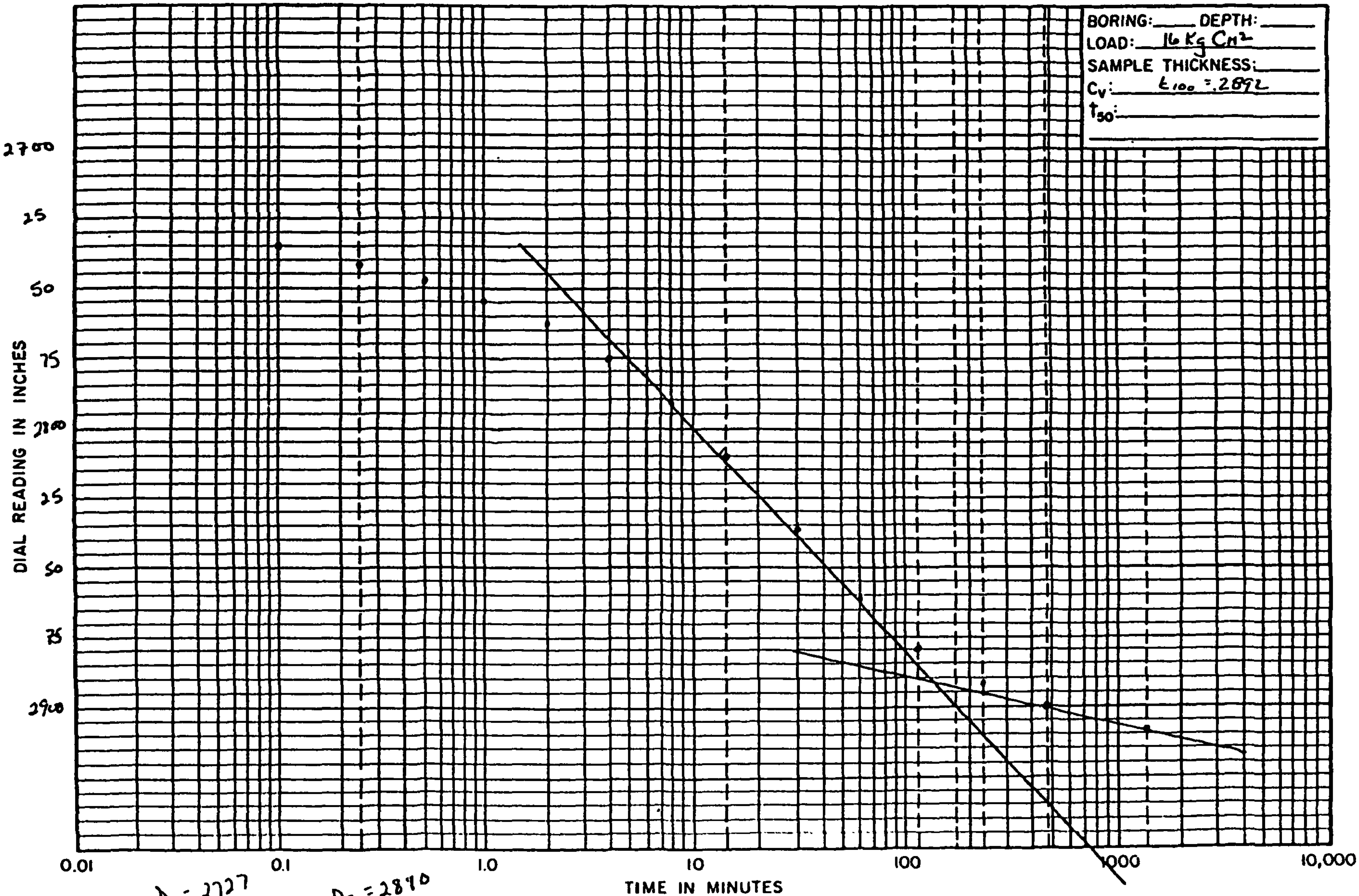


D0 = 2605
D100 = 2686
D50 = 2647

CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists

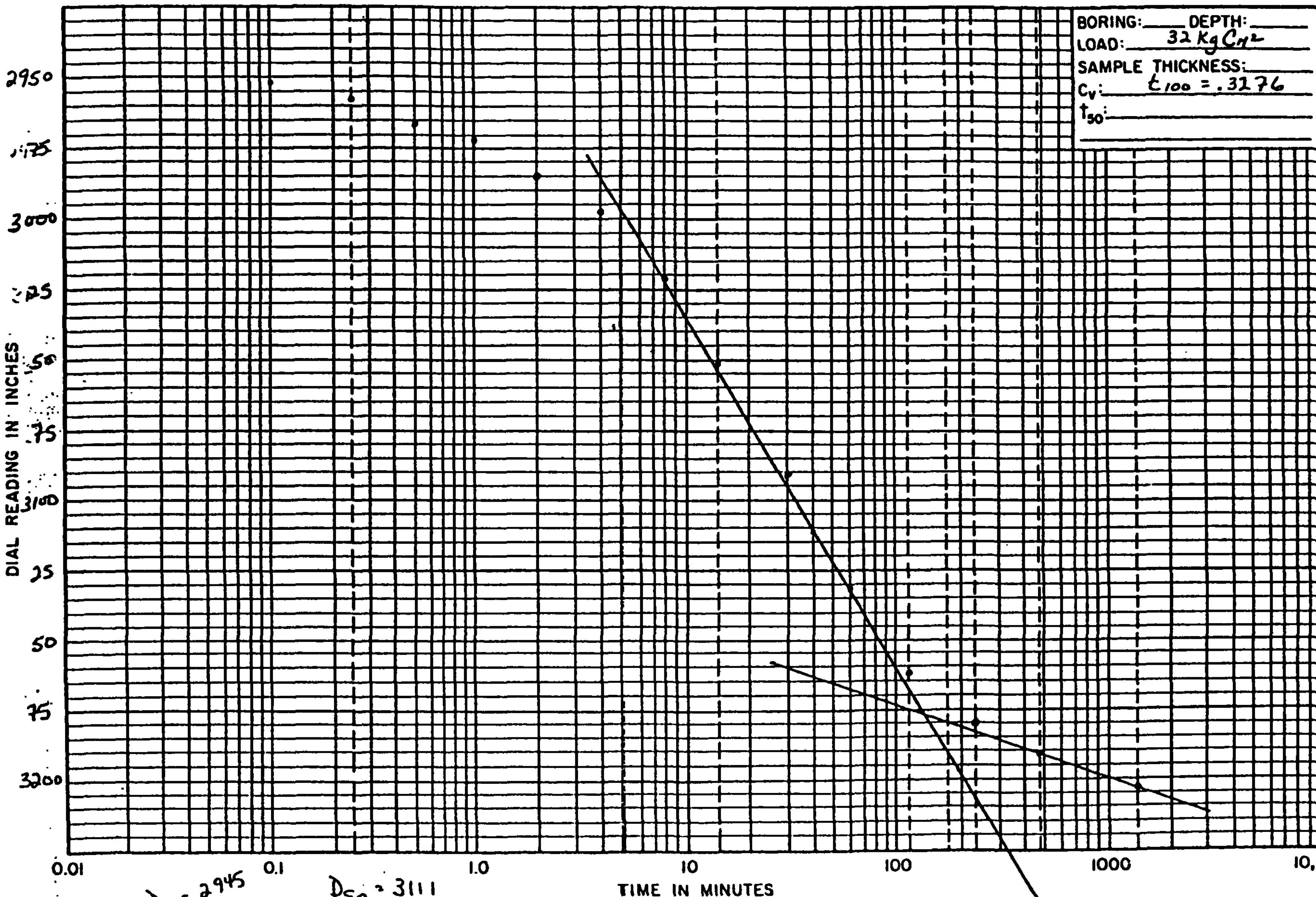


D_0 = 2727
D_{100} = 2892
D_{50} = 2810

CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists



CONSOLIDATION TIME CURVE

PLATE

CONSOLIDATION TEST
Version 1.1

JOB NO.: BORING NO.: SAMPLE NO.: DEPTH:

TEST SPECIMEN:

	INITIAL	FINAL
WET WEIGHT + TARE =	146.39	145.42
DRY WEIGHT + TARE =	130.43	130.43
TARE WEIGHT =	71.27	71.27
WATER CONTENT =	27.0%	25.3%

TRIMMINGS:

WET WEIGHT + TARE =	57.19
DRY WEIGHT + TARE =	48.65
TARE WEIGHT =	15.54
WATER CONTENT =	25.8%

SPECIFIC GRAVITY = 2.8000
SAMPLE HEIGHT (IN) = 0.7500
SAMPLE DIAMETER (IN) = 1.9700
SAMPLE VOLUME (CC) = 37.4681
HEIGHT OF SOLIDS (IN) = 0.4229
INITIAL VOID RATIO = 0.7733

DEGREE OF SATURATION:
INITIAL = 97.7%
FINAL = 101.0%

UNIT WEIGHT OF SPECIMEN:
WET (PCF) = 125.1
DRY (PCF) = 98.5

MACHINE READING	PRESSURE KG/CM^2	DIAL READING	CUM. CHANGE	CORR. CHANGE	VOID RATIO	COEFF. IN^2/DAY
-0.0054	4.000	0.2416	0.0084	0.0030	0.766	6.594
-0.0073	8.000	0.2314	0.0186	0.0113	0.747	4.836
-0.0095	16.000	0.2108	0.0392	0.0297	0.703	2.452
-0.0093	32.000	0.1724	0.0776	0.0683	0.612	0.824
-0.0100	8.000	0.1995	0.0505	0.0405	0.678	0.000
-0.0087	4.000	0.2112	0.0388	0.0301	0.702	0.000

BORING NO: SAMPLE NO:

DEPTH, FT: 78-79

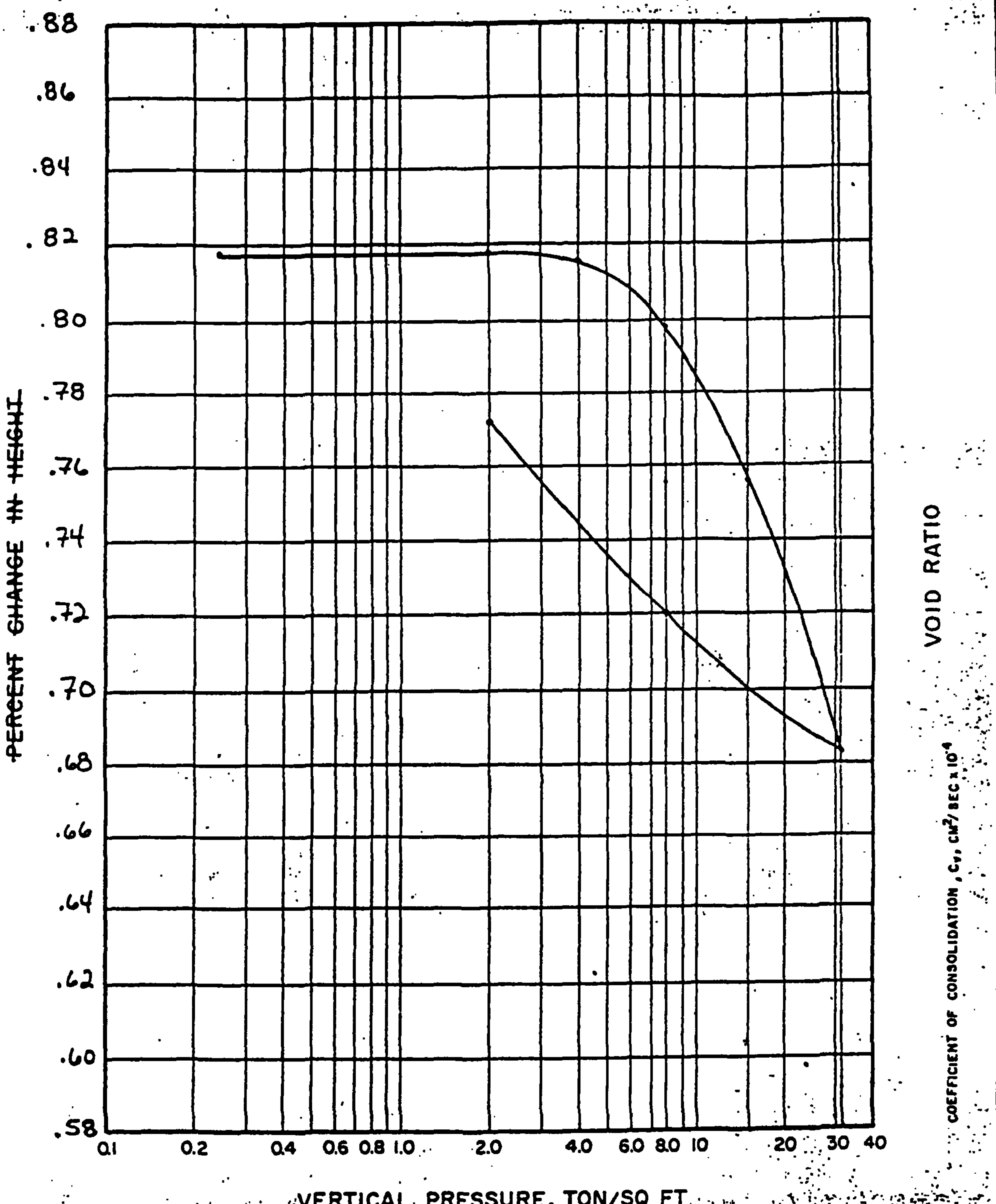
DESCRIPTION:

UNIT DRY WEIGHT: 96.1 PCF

WATER CONTENT: 28.4 %

LIQUID LIMIT:

PLASTIC LIMIT:



CONSOLIDATION TEST RESULTS

FUGRO GULF, INC.
Consulting Engineers and Geologists

PLATE

Job No.

FORM L-126

CONSOLIDATION TEST

Date: ______ Project: REI P10-4 Job No. ______

Boring No. ______ Sample No. ______ Depth: 78-80 Ring No. 1

Description: Very stiff red-light gray clay w/ calcareous nodules, slickensided

Liquid Limit ______

Plastic Limit ______

Test Specimen	Initial	Final
Wet wt sple + ring	133.81	132.94
Dry wt sple + ring	117.09	117.09
Wt of ring	59.38	59.38
Dry wt of sple		
Wt of water		
Water content, %	29.0	27.5

Trimmings, Can No. 473	
Wet wt + tare	51.53
Dry wt - tare	43.56
Tare wt	15.49
Dry wt	
Wt of water	
Water content, %	28.4

A. Specific Gravity 2.75 B. Volume of Sple 37.468 c.c. C. Initial Ht of Sple 0.750 in.

D. Final Ht of Sple ______ in. E. Unit Wet Wt 124.0 lb/ft^3 F. Unit Dry Wt 96.1 lb/ft^3

G. Ht of Solids = $\frac{\text{Final Dry Wt Sple}}{A} \times \frac{C}{B}$ = ______ in. $\frac{1}{G}$ = ______

H. Initial Void Ratio: = $\frac{C - G}{G}$ = 0.8179

d = 1.97

Percent Saturation:

Before Test = $\frac{\text{Initial Wt Water}}{B - \frac{\text{Dry Wt Sple}}{A}} \times 100$ = ______ %

After Test = $\frac{\text{Final Wt Water}}{B \times \frac{D}{C} - \frac{\text{Dry Wt Sple}}{A}} \times 100$ = ______ %

Consolidometer No: ______ *P = 70.9(C-J)^2/N

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v in.^{2}/day
.0000	—	.2520	—	—					
.0002	.25		—	—					
.0005	.5		—	—					
.0014	1		—	—					
.0030	2	.2503	.0017	—					
.0049	4	.2464	.0056	.0007			.816	3.75	10.62
.0070	8	.2368	.0152	.0082			.798	6.0	6.50
.0091	16	.2175	.0345	.0254			.756	14.0	2.66
.0115	32	.1850	.0670	.0555			.683	20.0	1.71
.0090	8	.2026	.0494	.0404			.720		
.0069	2	.2263	.0257	.0188			.772		

Tested By: [illegible]
Computed By: [illegible]
Checked By: [illegible]

CONSOLIDATION TEST
DATA SHEET

Job No. P10-4 Boring No. ______ Depth 78-79 Consol. No. 1

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.	Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
JZN	15 Aug	1145	0	.2520	.25KgCm²	JZN	16 Aug	0900	0	.2499	4KgCm²
			.1	.2516					.1	.2496	
			.25	.2515					.25	.2484	
			.5	.2514					.5	.2482	
	add H_2O →		1	.2513½					1	.2480	
			2	.2520	SWELL				2	.2478	
									4	.2476	
									8	.2473	
									15	.2470½	
JZN		1148	0	.2520	.5KgCm²				30	.2468	
			.1	.2519					60	.2466	
			.25	.2519					120	.2462½	
			.5	.2519					240	—	
			1	.2520				1700	480	.2461½	
			2	.2521	SWELL				1380	.2459	
						JZN	17 Aug	0800	0	.2459	8KgCm²
									.1	.2435	
JZN	15 Aug 86	1150	0	.2521	1.0KgCm²				.25	.2431	
			.1	.2518					.5	.2428	
			.25	.2517					1	.2423	
			.5	.2516½					2	.2418	
			1	.2516					4	.2410	
			2	.2516					8	.2401½	
			4	.2516					15	.2392	
			8	.2517½					30	.2381½	
			15	.2521	SWELL				60	.2373	
									120	.2368	
									240	.2364	
									480	.2361	
JZN	15 Aug 86	1205	0	.2521	2.0KgCm²		18 Aug	0835		.2357	
			.1	.2509							
			.25	.2507½							
			.5	.2506½		R.T.	19 Aug	0940	0	.2357	16KgCm²
			1	.2505½					.1	.2325	
			2	.2504½					.25	.2319	
			4	.2503½					.5	.2314	
			8	.2503					1	.2307	
			15	.2502½					2	.2297½	
			30	.2502					4	.2285	
			60	.2501½					8	.2267	
		1405	120	.2501					15	.2246	
		1605	240	.2500					35	.2215	
	16 Aug	0800		.2499					60	.2196	
								1140	120	2178	
								1340	240	.2166	
								1640	420	.2161	
								0810		2149	

FORM L-126

CONSOLIDATION TEST

Date:________ Project:________ Job No.________

Boring No.________ Sample No.________ Depth:________ Ring No.________

Description:________ Liquid Limit________

Plastic Limit________

Test Specimen	Initial	Final
Wet wt sple + ring		
Dry wt sple + ring		
Wt of ring		
Dry wt of sple		
Wt of water		
Water content, %		

Trimmings, Can No.	
Wet wt + tare	
Dry wt - tare	
Tare wt	
Dry wt	
Wt of water	
Water content, %	

A. Specific Gravity________ B. Volume of Sple________ c.c. C. Initial Ht of Sple________ in.

D. Final Ht of Sple________ in. E. Unit Wet Wt________ lb/ft^3 F. Unit Dry Wt________ lb/ft^3

G. Ht of Solids = $\frac{\text{Final Dry Wt Sple}}{A} \times \frac{C}{B}$ = ________ in. $\frac{1}{G}$ = ________

H. Initial Void Ratio: = $\frac{C - G}{G}$ = ________

Percent Saturation:

Before Test = $\frac{\text{Initial Wt Water}}{B - \frac{\text{Dry Wt Sple}}{A}} \times 100$ = ________ %

After Test = $\frac{\text{Final Wt Water}}{B \times \frac{D}{C} - \frac{\text{Dry Wt Sple}}{A}} \times 100$ = ________ %

Consolidometer No: $^{*}P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v $in.^2/day$

Tested By:________
Computed By:________
Checked By:________

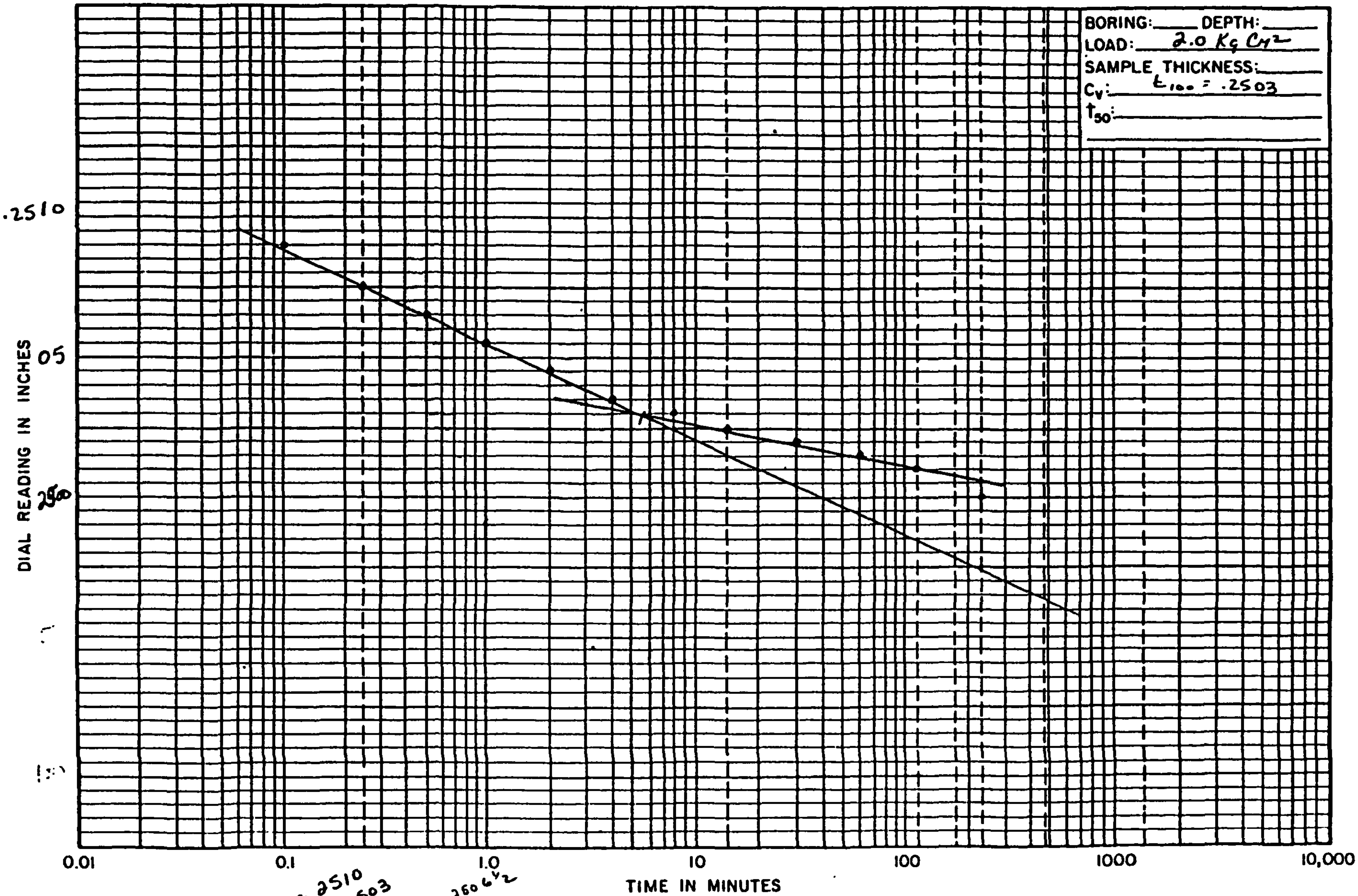
CONSOLIDATION TEST
DATA SHEET

Job No. ____________ Boring No. ____________ Depth ____________ Consol. No. ____________

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.	Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
B.T.	20 Aug	0815	0	.2119	32 Kg/cm²						
			.1	.2117							
			.25	.2110							
			.50	.2104							
			1	.2095							
			2	.2082							
			4	.2064							
			8	.2039							
			15	.2009							
			30	.1968							
			60	.1918							
		1030	~~120~~135	.1875							
			240	.1855							
		420	485	.1840							
		0820		.1826							
	Rebound		0								
	21 Aug	0835	0	.1826	8 Kg/cm²						
	22 Aug	1130		.2026							
	22 Aug	1130	0	.2026	2 Kg/cm²						
				.2263							

Job No. ______ FORM L-127

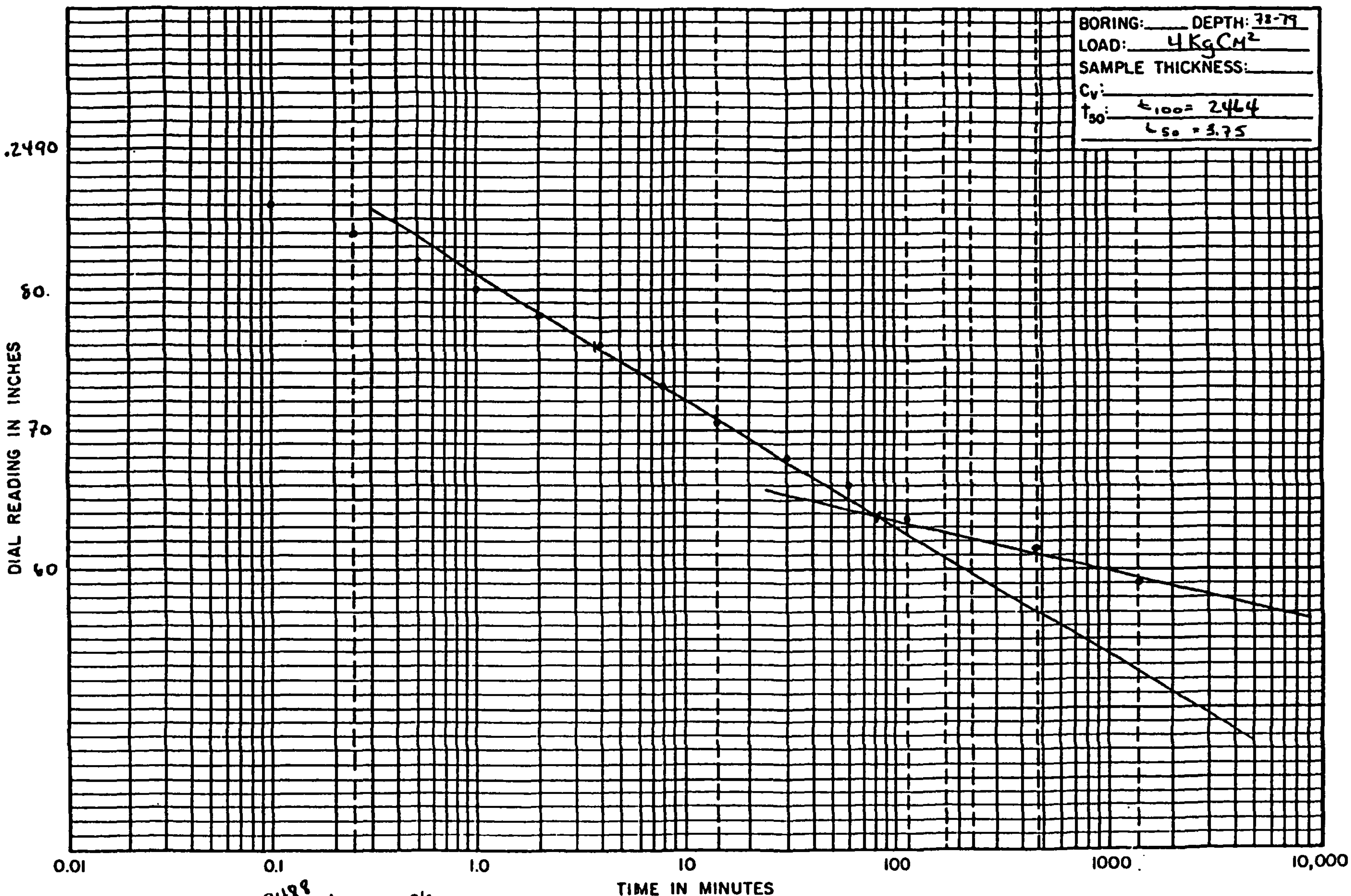
FUGRO GULF, INC.
Consulting Engineers and Geologists



CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists

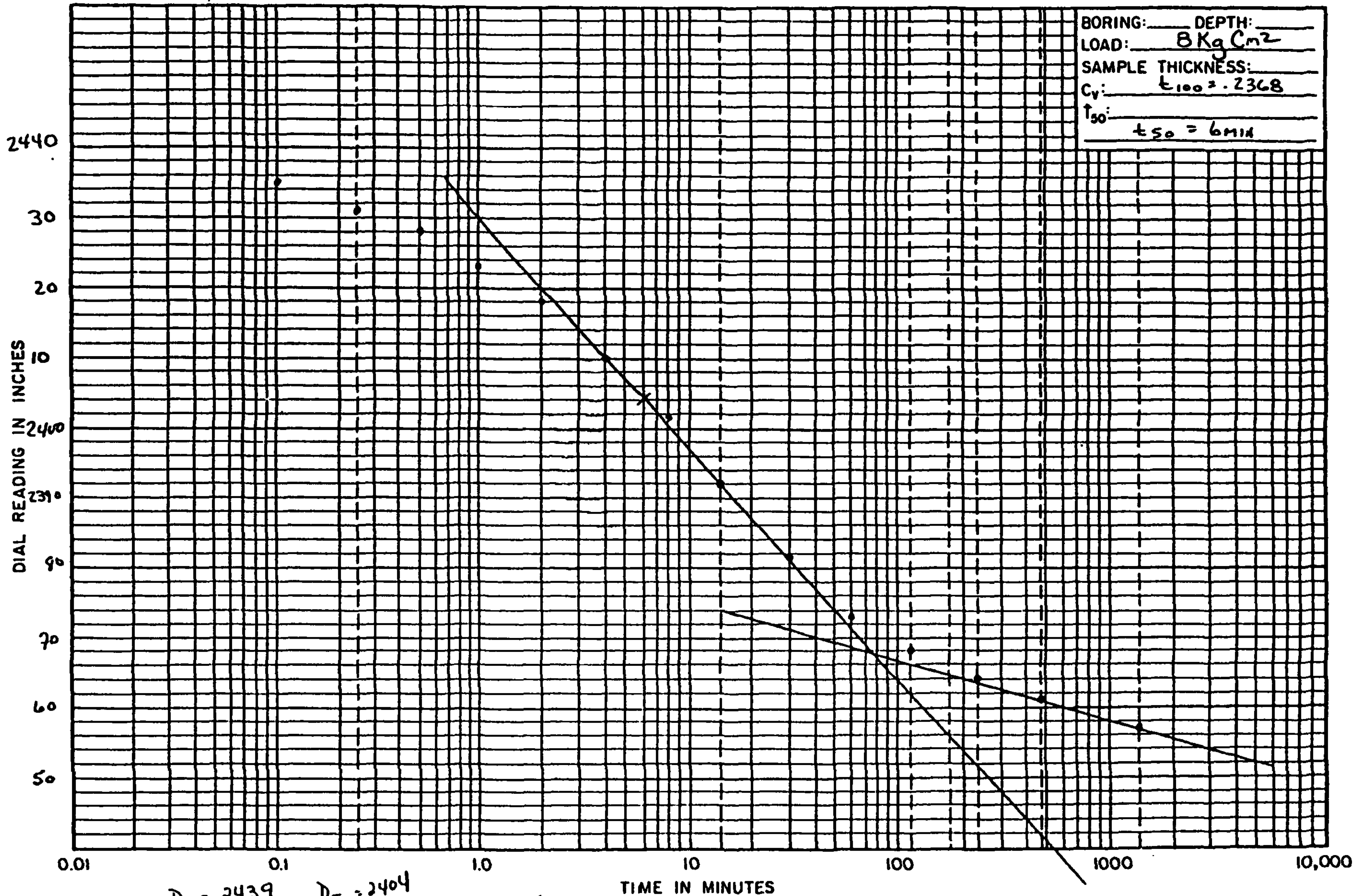


Do = 2488
t100 = 2464
D50 = 2476

CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists



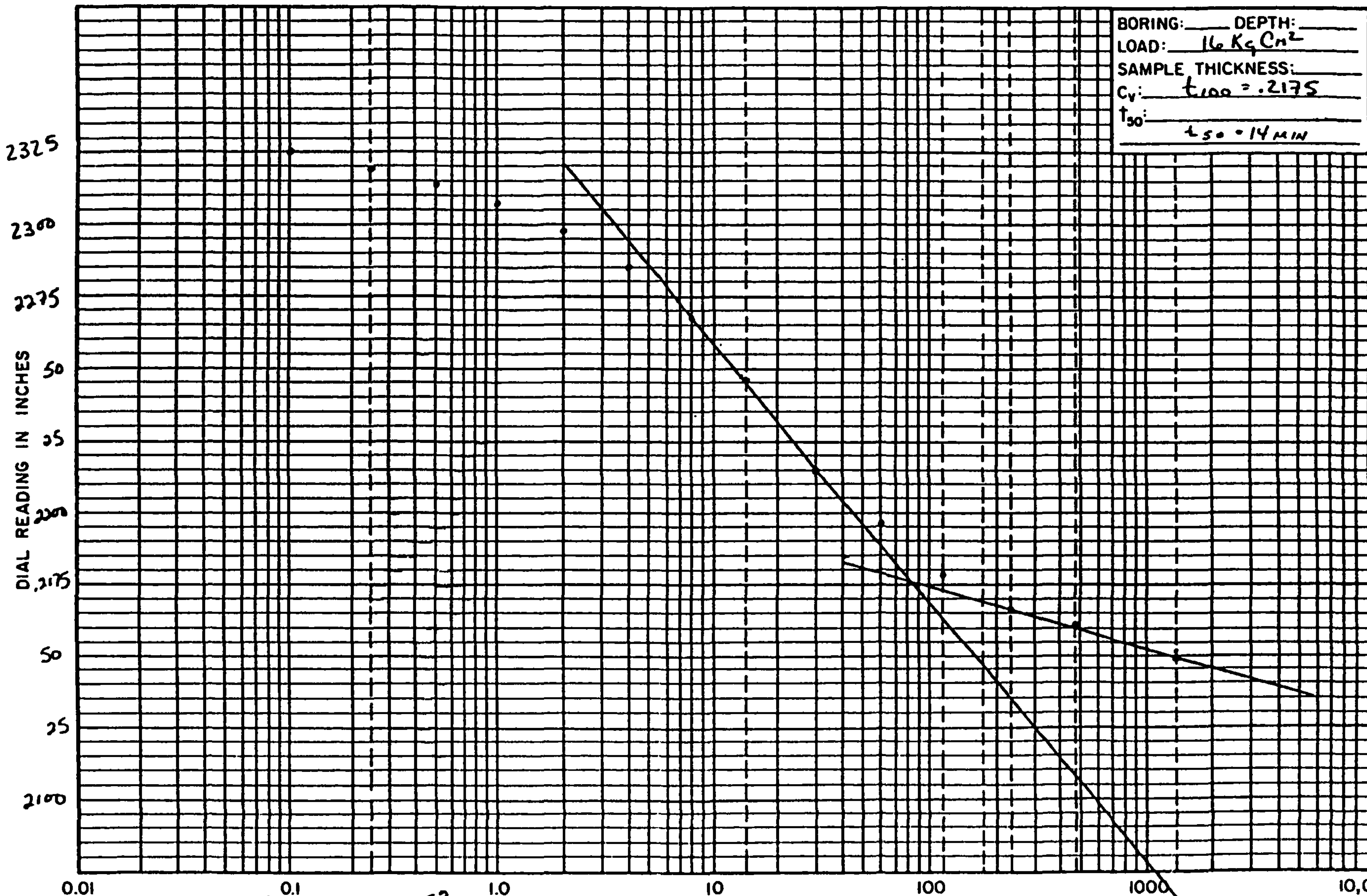
D_0 = 2439 D_{50} = 2404
D_{100} 2368

CONSOLIDATION TIME CURVE

PLATE

Job No.

FUGRO GULF, INC.
Consulting Engineers and Geologists



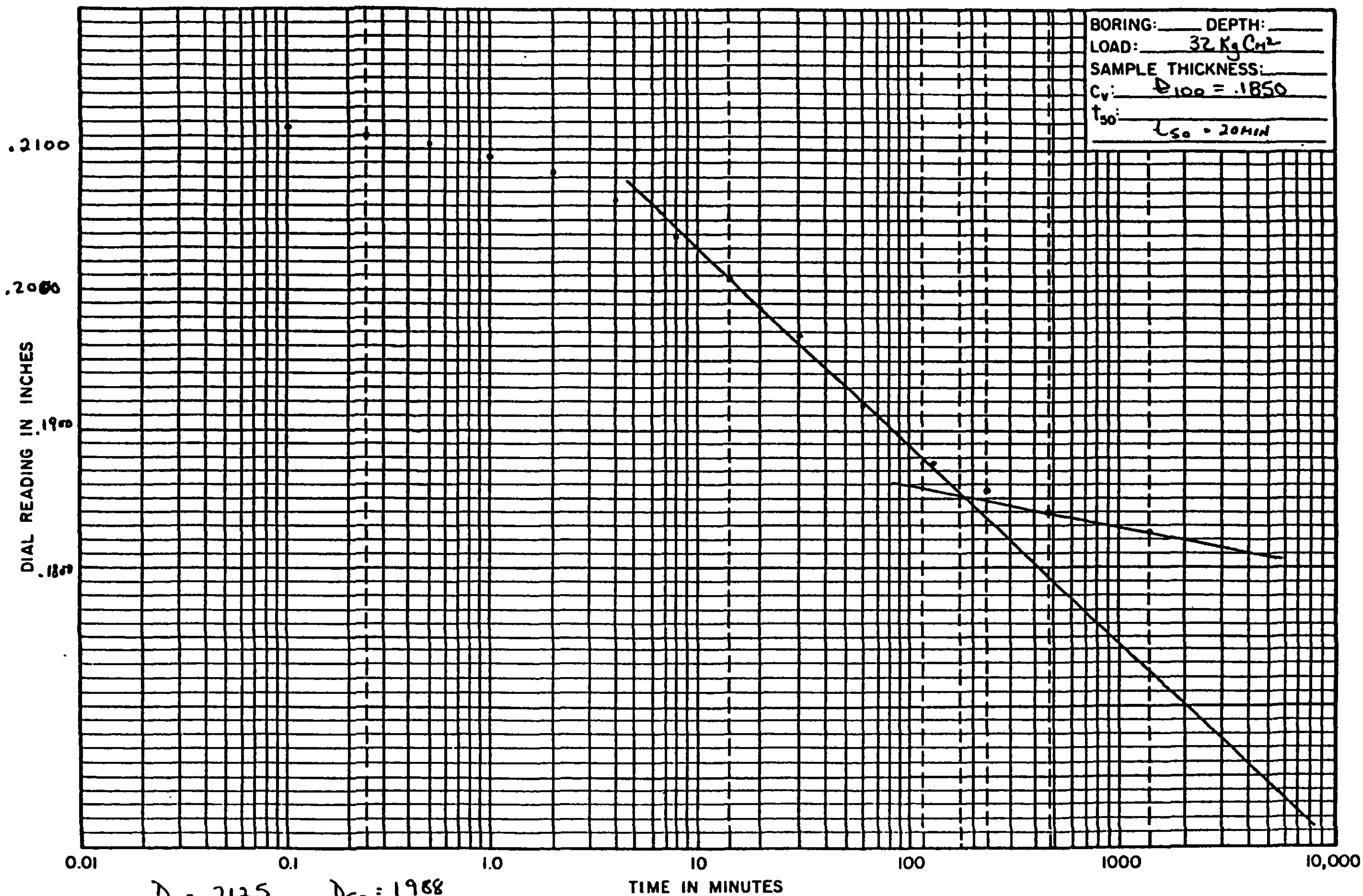
$D_0 = .2331$ $D_{50} = 2253$
$D_{100} = .2175$

CONSOLIDATION TIME CURVE

PLATE

JOB NO.

FUGRO GULF, INC.
Consulting Engineers and Geologists



D_0 = 2125 D_{50} : 1988
D_{100} = 1850

CONSOLIDATION TIME CURVE

PLATE

CONSOLIDATION TEST
Version 1.1

JOB NO.: BORING NO.: SAMPLE NO.: DEPTH:

TEST SPECIMEN:

	INITIAL	FINAL
WET WEIGHT + TARE =	133.81	132.94
DRY WEIGHT + TARE =	117.09	117.09
TARE WEIGHT =	59.38	59.38
WATER CONTENT =	29.0%	27.5%

TRIMMINGS:

WET WEIGHT + TARE =	51.53
DRY WEIGHT + TARE =	43.56
TARE WEIGHT =	15.49
WATER CONTENT =	28.4%

SPECIFIC GRAVITY = 2.8000
SAMPLE HEIGHT (IN) = 0.7500
SAMPLE DIAMETER (IN) = 1.9700
SAMPLE VOLUME (CC) = 37.4681
HEIGHT OF SOLIDS (IN) = 0.4126
INITIAL VOID RATIO = 0.8179

DEGREE OF SATURATION:
INITIAL = 99.2%
FINAL = 99.6%

UNIT WEIGHT OF SPECIMEN:
WET (PCF) = 124.0
DRY (PCF) = 96.1

MACHINE READING	PRESSURE KG/CM^2	DIAL READING	CUM. CHANGE	CORR. CHANGE	VOID RATIO	COEFF. IN^2/DAY
-0.0049	4.000	0.2464	0.0056	0.0007	0.816	10.615
-0.0070	8.000	0.2368	0.0152	0.0082	0.798	6.502
-0.0091	16.000	0.2175	0.0345	0.0254	0.756	2.659
-0.0115	32.000	0.1850	0.0670	0.0555	0.683	1.710
-0.0090	8.000	0.2026	0.0494	0.0404	0.720	0.000
-0.0069	2.000	0.2263	0.0257	0.0188	0.772	0.000

BORING NO: SAMPLE NO:

DEPTH, FT: 80-81

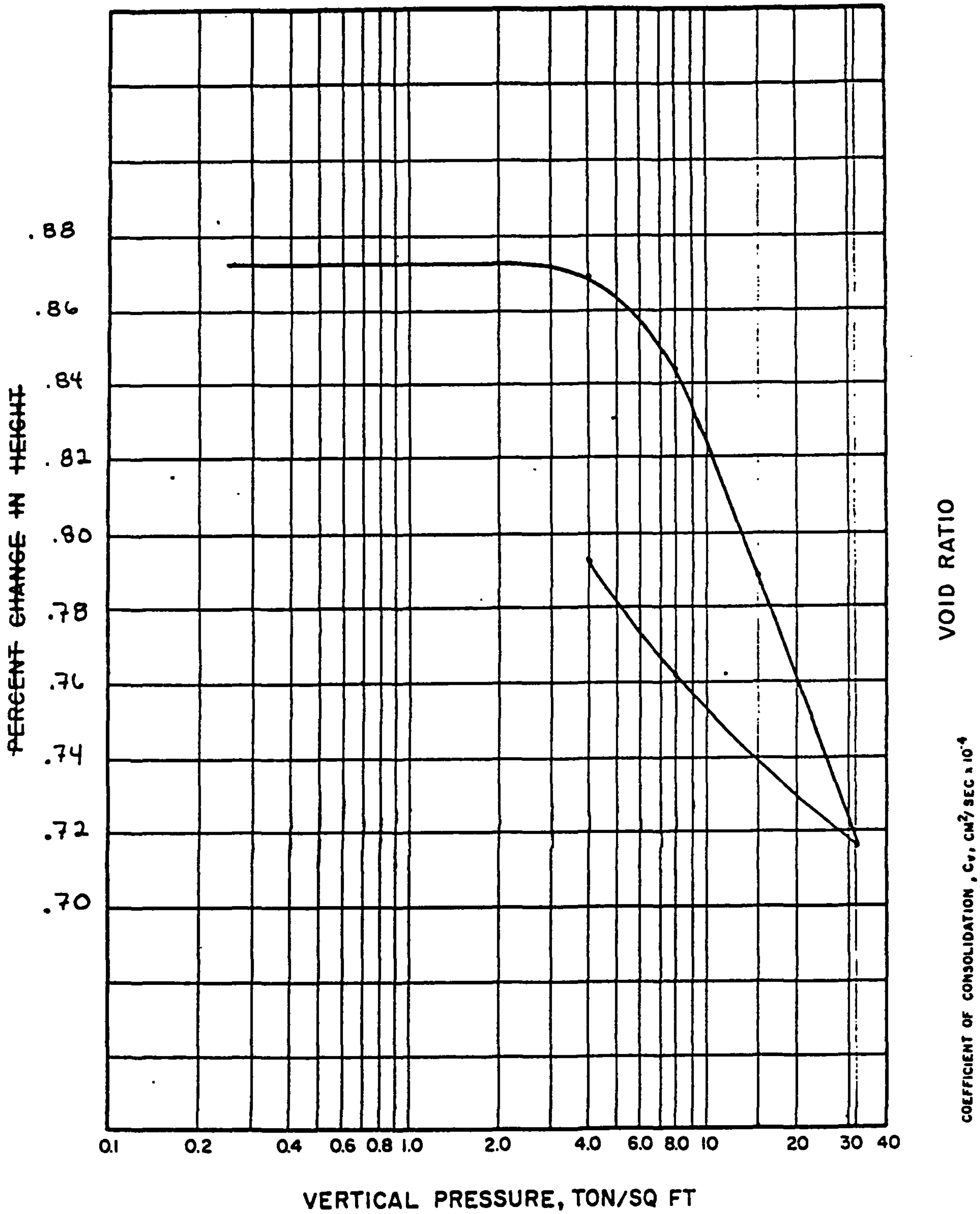
DESCRIPTION: Hard red clay with calcareous nodules, slickensided

UNIT DRY WEIGHT: 93.3 PCF

WATER CONTENT: 27.7 %

LIQUID LIMIT:

PLASTIC LIMIT:



CONSOLIDATION TEST RESULTS

CONSOLIDATION TEST

Date: ______ Project: REI P10-4 Job No. ______

Boring No. ______ Sample No. ______ Depth: 80 - 81 Ring No. 3

Description: Vst. red clay w/calc NODS, SLICKENSIDED

Liquid Limit ______

Plastic Limit ______

Test Specimen	Initial	Final
Wet wt sple + ring	143.75	142.50
Dry wt sple + ring	126.28	126.28
Wt of ring	70.50	70.50
Dry wt of sple		
Wt of water		
Water content, %		

Trimmings, Can No. 605	
Wet wt + tare	64.32
Dry wt - tare	53.67
Tare wt	15.09
Dry wt	
Wt of water	
Water content, %	

A. Specific Gravity ______ B. Volume of Sple 37.318 c.c. C. Initial Ht of Sple 0.747 in.

D. Final Ht of Sple ______ in. E. Unit Wet Wt ______ lb/ft^3 F. Unit Dry Wt ______ lb/ft^3

G. Ht of Solids $= \frac{\text{Final Dry Wt Sple}}{A} \times \frac{C}{B} =$ 0.3988 in. $\frac{1}{G} =$ ______

H. Initial Void Ratio: $= \frac{C - G}{G} =$ 0.8733

d = 1.97

Percent Saturation:

Before Test $= \dfrac{\text{Initial Wt Water}}{B - \frac{\text{Dry Wt Sple}}{A}} \times 100 =$ ______ %

After Test $= \dfrac{\text{Final Wt Water}}{B \times \frac{D}{C} - \frac{\text{Dry Wt Sple}}{A}} \times 100 =$ ______ %

Consolidometer No:

*$P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v $in.^2/day$
.0000	0	.2500	—	—					
.0003	.25		—	—					
.0007	.5		—	—					
.0017	1		—	—					
.0035	2		—	—					
.0060	4	.2576	.0076	.0016			0.869	5.5	7.162
.0087	8	.2705	.0205	.0118			0.844	18.0	2.129
.0110	16	.2945	.0445	.0335			0.789	26.0	1.388
.0134	32	.3260	.0760	.0626			0.716	28.0	1.186
.0107	8	.3052	.0552	.0445			0.762		
.0090	4	.2911	.0411	.0321			0.793		

Tested By: [illegible]
Computed By: [illegible]
Checked By: REY

CONSOLIDATION TEST
DATA SHEET

Job No. ______ Boring No. P10-4 Depth 80-81 Consol. No. 3

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.	Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
JJN	15Aug	1308	0	.2500	.25KgCm²	JJN	15Aug	1330	0	.2520	4.0KgCm²
			.1	.2508					.1	.2551	
			.25	.2509					.25	.2553½	
			.5	.2510					.5	.2556	
	add	H2O →	1	.2510					1	.2558½	
			2	.2500	SWELL				2	.2561	
			"						4	.2564	
									8	.2568½	
									15	.2571	
									30	.2574½	
								1430	60	.2575½	
JJN		1310	0	.2500	.5KgCm²			1530	120	.2577	
			.1	.2504				1730	240	.2578	
			.25	.2505			16Aug	0800	1110	.2580	
			.5	.2504							
			1	.2503							
			2	.2501	SWELL						
							16Aug	0910	0	.2580	8KgCm²
									.1	.2609	
		1313	0	.2501	1.0KgCm²				.25	.2612	
			.1	.2510					.5	.2616	
			.25	.2511					1	.2620½	
			.5	.2511½					2	.2626	
			1	.2511½					4	.2633½	
			2	.2511					8	.2643	
			4	.2510	SWELL				15	.2654	
									30	.2667	
									60	.2682	
JJN	15Aug	1315	0	.2510	2.0KgCm²				120	.2699	
			.1	.2525½					240	~~[illegible]~~	
			.25	.2527					480	.2709	
			.5	.2528½					1440	.2714	
			1	.2529½							
			2	.2530½							
			4	.2531			17Aug	0810	0	.2714	16KgCm²
			8	.2530					.1	.2748	
			15		SWELL				.25	.2752	
									.5	.2757	
									1	.2763	
									2	.2772	
									4	.2784	
									8	.2800	
									15	.2821	
									30	.2850	
									60	.2884	
									120	.2915	
									240	.2938	
									480	.2952	
								0830	1460	.2963	

CONSOLIDATION TEST

Date: ________ Project: ________ Job No. ________

Boring No. ______ Sample No. ______ Depth: ______ Ring No. ______

Description: ________ Liquid Limit ______

________ Plastic Limit ______

Test Specimen	Initial	Final
Wet wt sple + ring		
Dry wt sple + ring		
Wt of ring		
Dry wt of sple		
Wt of water		
Water content, %		

Trimmings, Can No.	
Wet wt + tare	
Dry wt - tare	
Tare wt	
Dry wt	
Wt of water	
Water content, %	

A. Specific Gravity ______ B. Volume of Sple ______ c.c. C. Initial Ht of Sple ______ in.

D. Final Ht of Sple ______ in. E. Unit Wet Wt ______ lb/ft^3 F. Unit Dry Wt ______ lb/ft^3

G. Ht of Solids $= \frac{\text{Final Dry Wt Sple}}{A} \times \frac{C}{B} =$ ______ in. $\frac{1}{G} =$ ______

H. Initial Void Ratio: $= \frac{C - G}{G} =$ ______

Percent Saturation:

Before Test $= \dfrac{\text{Initial Wt Water}}{B - \frac{\text{Dry Wt Sple}}{A}} \times 100 =$ ______ %

After Test $= \dfrac{\text{Final Wt Water}}{B \times \frac{D}{C} - \frac{\text{Dry Wt Sple}}{A}} \times 100 =$ ______ %

Consolidometer No: $^*P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v $in.^2/day$

Tested By: ______
Computed By: ______
Checked By: ______

CONSOLIDATION TEST
DATA SHEET

Job No. ________ Boring No. ________ Depth ________ Consol. No. ________

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.	Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
B.T.	18 aug	0845	0	.2963	32 Kg/cm²						
			.1	.2995							
			.25	.3001							
			.5	.3008							
			1	.3016							
			2	.3027							
			4	.3043							
			8	.3064							
			15	.3090							
			30	.3128½							
			60	.3177							
			120	.3225							
		1225	220	.3256							
		1700	495	.3278							
	19 Aug	0924		.3298							
	Rebound										
B.T.	19 Aug	0930	0	.3298	8 Kg/cm²						
		0810		.3052							
B.T.	20 Aug	0810	0	.3052	4 Kg/cm²						
B.T.	21 Aug	0820		.2911							

FUGRO GULF, INC.
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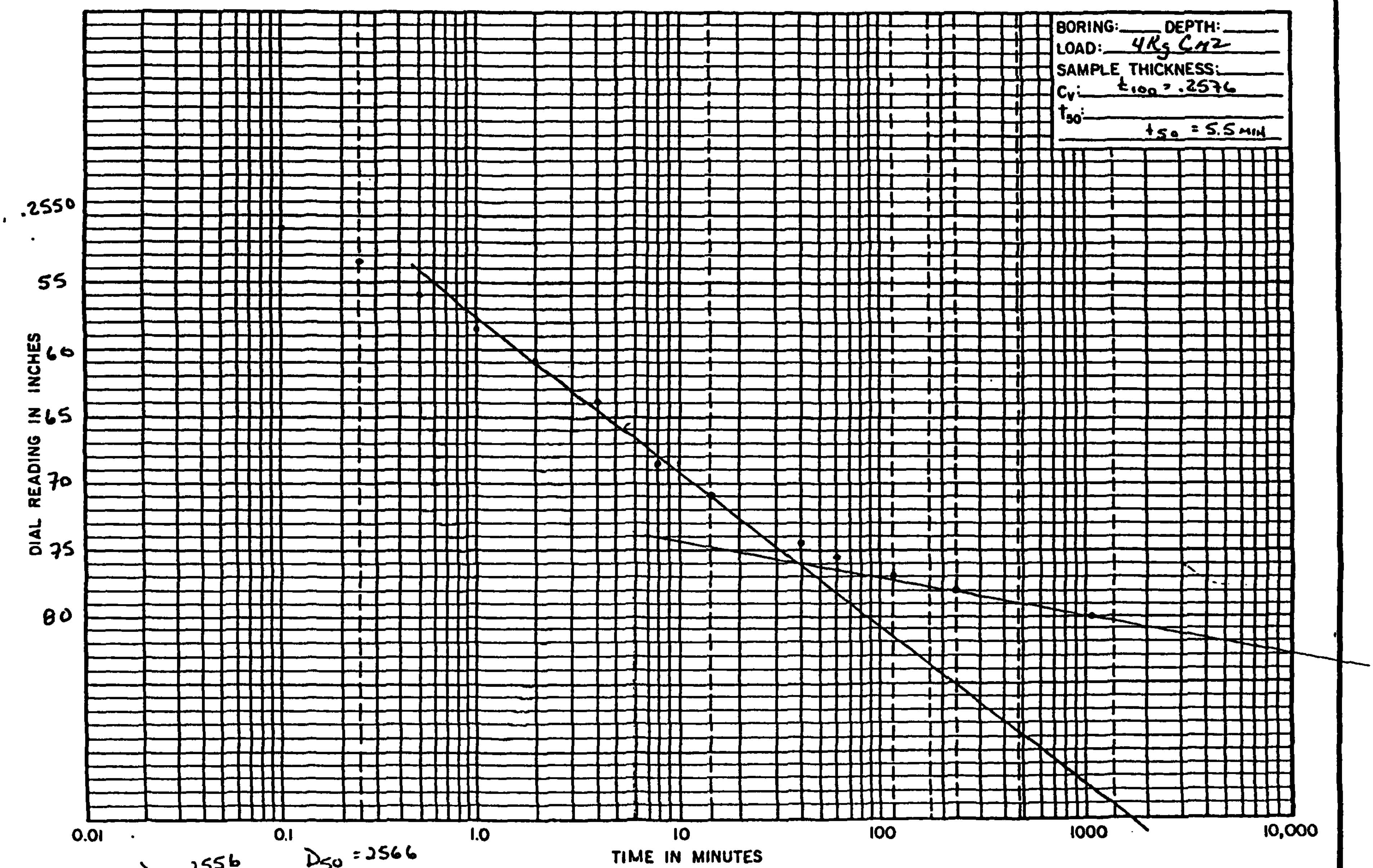
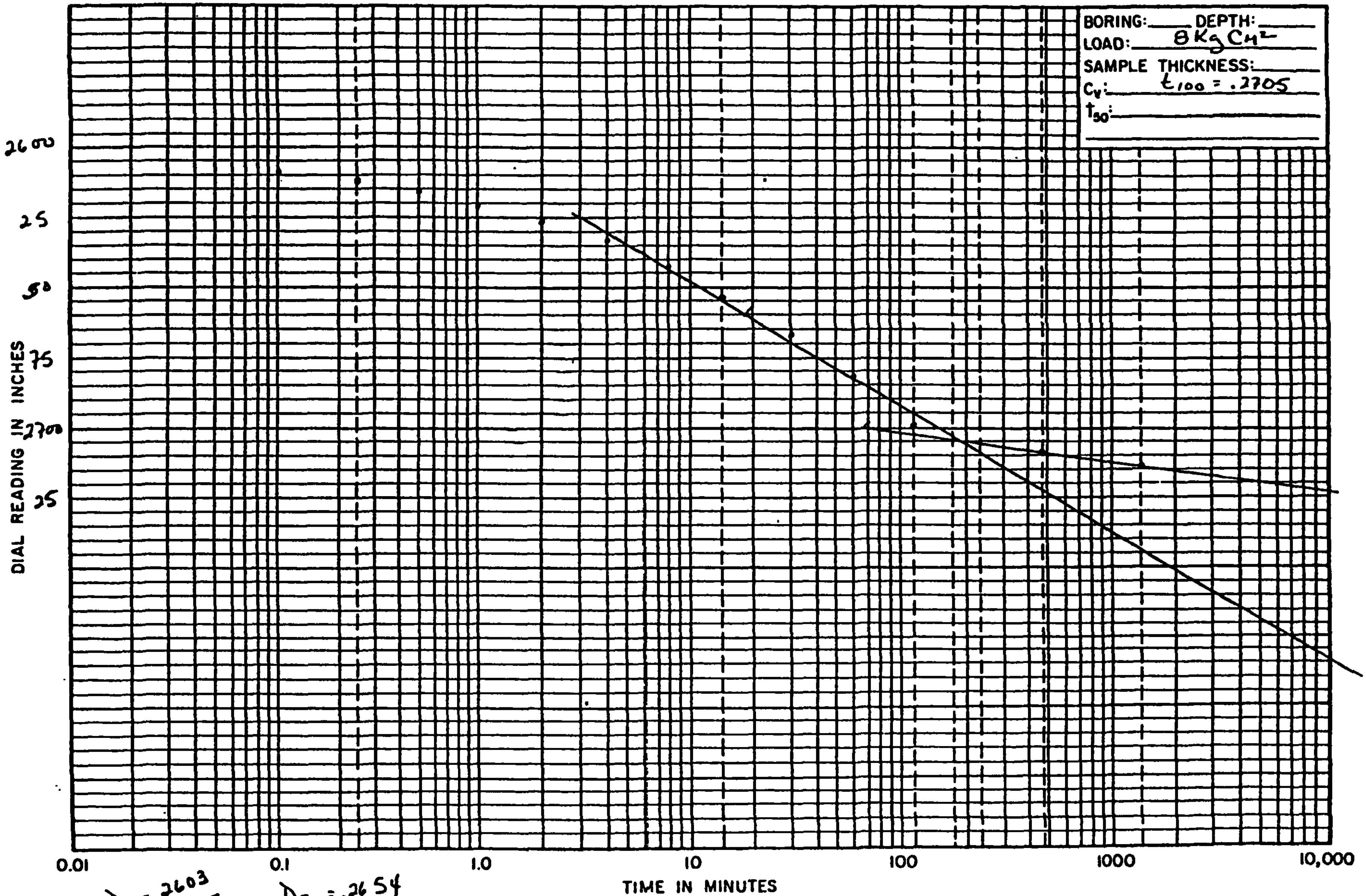


D_o = 2556
D_{100} 2576
D_{50} = 2566

CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists

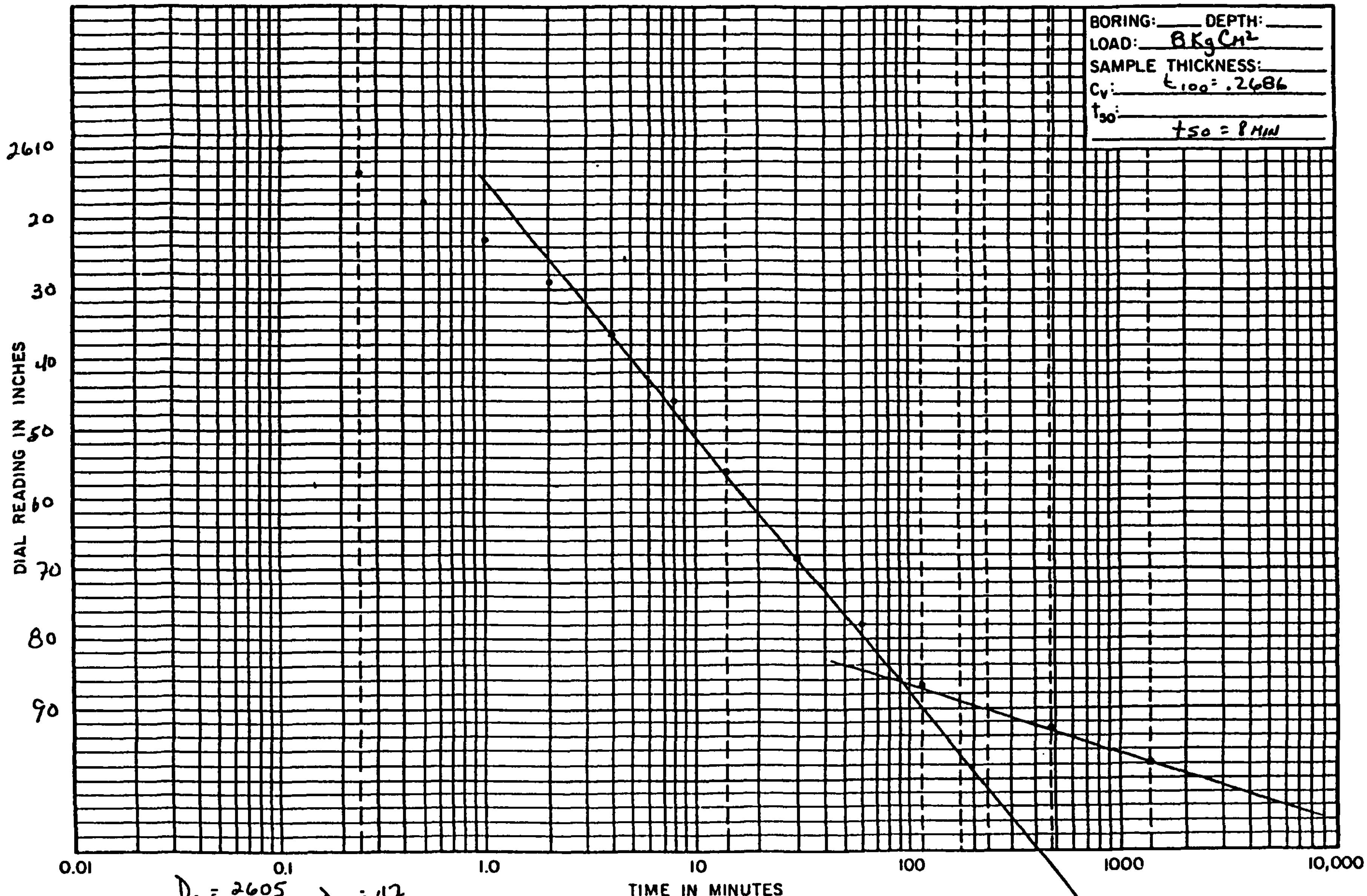


$D_0 = 2603$
$D_{100} = 2705$
$D_{50} = .2654$

CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists



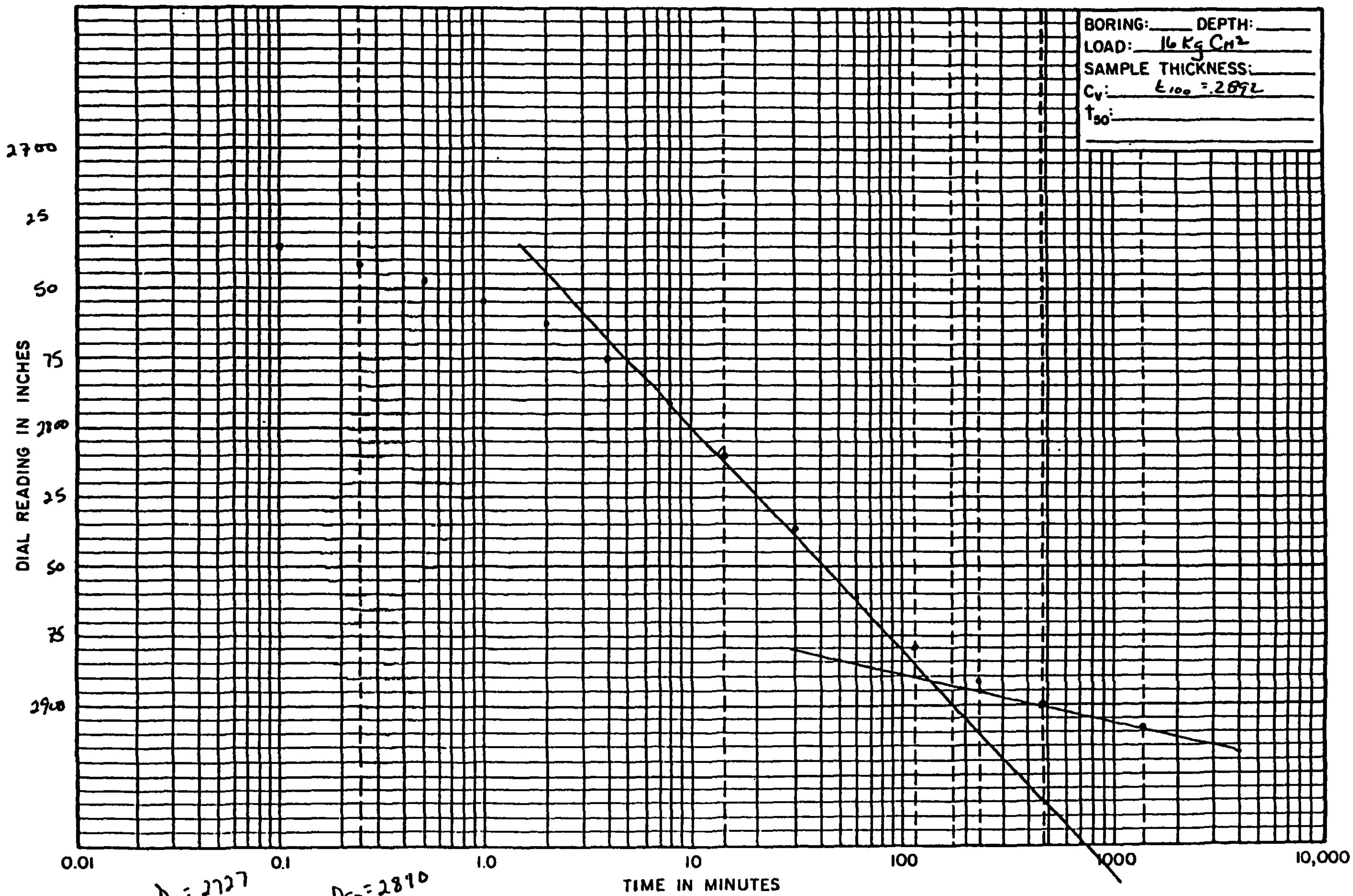
$D_o = 2605$ $D_{50} = 2647$

$D_{100} = 2686$

CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists

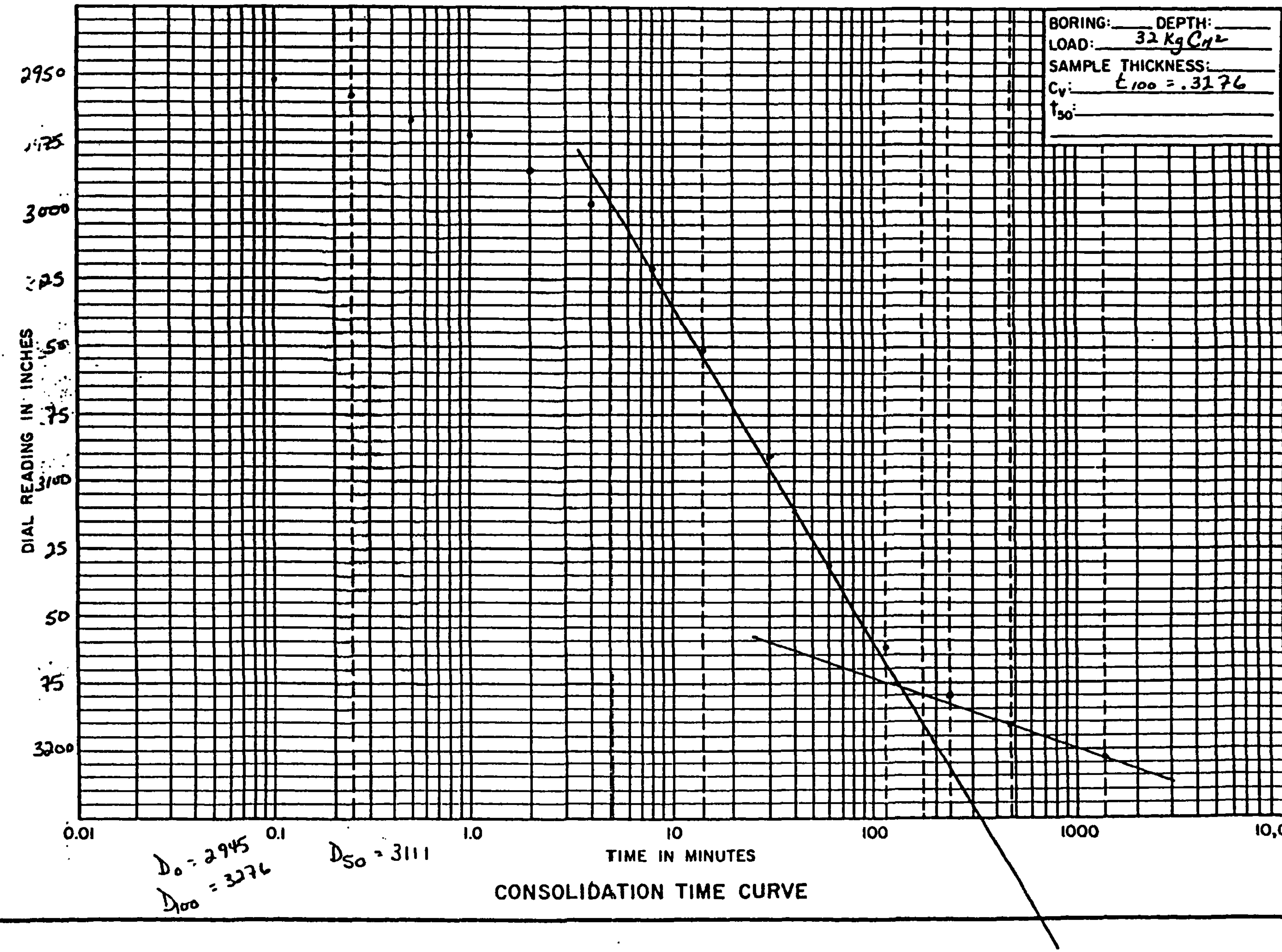


D_o = 2727
D_{100} = 2892
D_{50} = 2810

CONSOLIDATION TIME CURVE

PLATE

FUGRO GULF, INC.
Consulting Engineers and Geologists



CONSOLIDATION TIME CURVE

PLATE

CONSOLIDATION TEST

Version 1.1

JOB NO.: BORING NO.: SAMPLE NO.: DEPTH:

TEST SPECIMEN:

	INITIAL	FINAL
WET WEIGHT + TARE =	146.39	145.42
DRY WEIGHT + TARE =	130.43	130.43
TARE WEIGHT =	71.27	71.27
WATER CONTENT =	27.0%	25.3%

TRIMMINGS:

WET WEIGHT + TARE = 57.19
DRY WEIGHT + TARE = 48.65
TARE WEIGHT = 15.54
WATER CONTENT = 25.8%

SPECIFIC GRAVITY = 2.8000
SAMPLE HEIGHT (IN) = 0.7500
SAMPLE DIAMETER (IN) = 1.9700
SAMPLE VOLUME (CC) = 37.4681
HEIGHT OF SOLIDS (IN) = 0.4229
INITIAL VOID RATIO = 0.7733

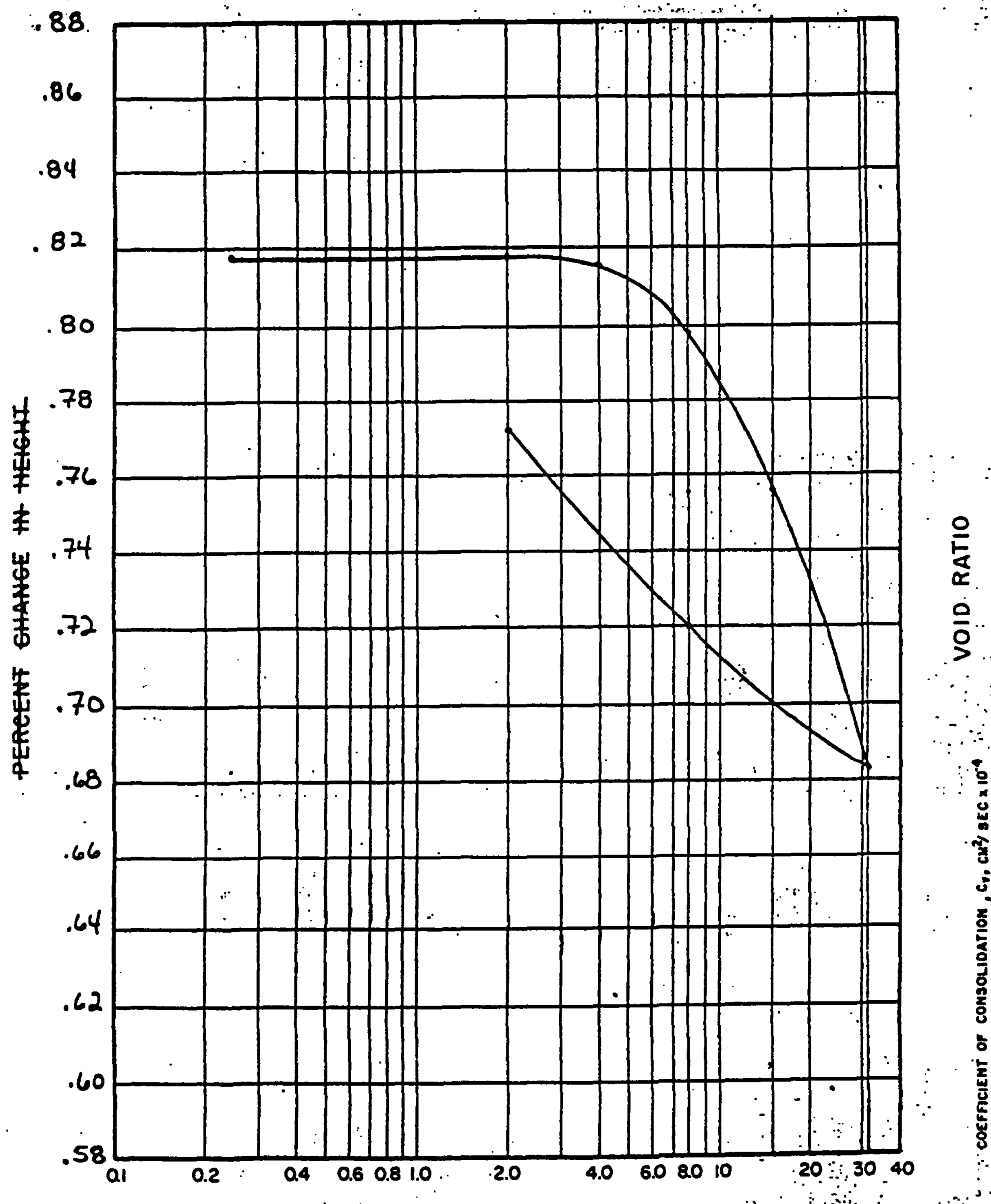
DEGREE OF SATURATION:
INITIAL = 97.7%
FINAL = 101.0%

UNIT WEIGHT OF SPECIMEN:
WET (PCF) = 125.1
DRY (PCF) = 98.5

MACHINE READING	PRESSURE KG/CM^2	DIAL READING	CUM. CHANGE	CORR. CHANGE	VOID RATIO	COEFF. IN^2/DAY
-0.0054	4.000	0.2416	0.0084	0.0030	0.766	6.594
-0.0073	8.000	0.2314	0.0186	0.0113	0.747	4.836
-0.0095	16.000	0.2108	0.0392	0.0297	0.703	2.452
-0.0093	32.000	0.1724	0.0776	0.0683	0.612	0.824
-0.0100	8.000	0.1995	0.0505	0.0405	0.678	0.000
-0.0087	4.000	0.2112	0.0388	0.0301	0.702	0.000

BORING NO: SAMPLE NO:
DEPTH, FT: 78-79
DESCRIPTION:

UNIT DRY WEIGHT: 96.1 PCF
WATER CONTENT: 28.4 %
LIQUID LIMIT:
PLASTIC LIMIT:



CONSOLIDATION TEST RESULTS

FUGRO GULF, INC.
Consulting Engineers and Geologists

PLATE

FORM L-126

CONSOLIDATION TEST

Date: ________ Project: REI P10-4 Job No. ________

Boring No. ________ Sample No. ________ Depth: 78-80 Ring No: 1

Description: Very stiff red - light gray clay w/ calcareous nodules, slickensided

Liquid Limit ________

Plastic Limit ________

Test Specimen	Initial	Final
Wet wt sple + ring	133.81	132.94
Dry wt sple + ring	117.09	117.09
Wt of ring	59.38	59.38
Dry wt of sple		
Wt of water		
Water content, %	29.0	27.5

Trimmings, Can No. 473	
Wet wt + tare	51.53
Dry wt - tare	43.56
Tare wt	15.49
Dry wt	
Wt of water	
Water content, %	28.4

A. Specific Gravity 2.75 B. Volume of Sple 37.468 c.c. C. Initial Ht of Sple 0.750 in.

D. Final Ht of Sple ________ in. E. Unit Wet Wt 124.0 lb/ft³ F. Unit Dry Wt 96.1 lb/ft³

G. Ht of Solids = $\frac{\text{Final Dry Wt Sple}}{A} \times \frac{C}{B}$ = ________ in. $\frac{1}{G}$ = ________

H. Initial Void Ratio: = $\frac{C - G}{G}$ = 0.8179

d = 1.97

Percent Saturation:

Before Test = $\frac{\text{Initial Wt Water}}{B - \frac{\text{Dry Wt Sple}}{A}} \times 100$ = ________ %

After Test = $\frac{\text{Final Wt Water}}{B \times \frac{D}{C} - \frac{\text{Dry Wt Sple}}{A}} \times 100$ = ________ %

Consolidometer No:

*$P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft²	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N = t_{50} min.	P* c_v in.²/day
.0000	—	.2520	—	—					
.0002	.25		—	—					
.0005	.5		—	—					
.0014	1		—	—					
.0030	2	.2503	.0017	—					
.0049	4	.2464	.0056	.0007			.816	3.75	10.62
.0070	8	.2368	.0152	.0082			.798	6.0	6.50
.0091	16	.2175	.0345	.0254			.756	14.0	2.66
.0115	32	.1850	.0670	.0555			.683	20.0	1.71
.0090	8	.2026	.0494	.0404			.720		
.0069	2	.2263	.0257	.0188			.772		

Tested By: ________
Computed By: ________
Checked By: ________

CONSOLIDATION TEST
DATA SHEET

Job No. P10-4 Boring No. ______ Depth 78-79 Consol. No. 1

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.	Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
JZN	15Aug	1145	0	.2520	.25KgCm²	JZN	16Aug	0900	0	.2499	4KgCm²
			.1	.2516					.1	.2486	
			.25	.2515					.25	.2484	
			.5	.2514					.5	.2482	
	add H_2O →		1	.2513½					1	.2480	
			2	.2520	SWELL				2	.2478	
									4	.2476	
									8	.2473	
									15	.2470½	
JZN		1148	0	.2520	.5KgCm²				30	.2468	
			.1	.2519					60	.2466	
			.25	.2519					120	.2463½	
			.5	.2519					240		
			1	.2520				1700	480	.2461½	
			2	.2521	SWELL				1380	.2459	
						JZN	17Aug	0800	0	.2459	8KgCm²
									.1	.2435	
JZN	15Aug86	1150	0	.2521	1.0KgCm²				.25	.2431	
			.1	.2518					.5	.2428	
			.25	.2517					1	.2423	
			.5	.2516½					2	.2418	
			1	.2516					4	.2410	
			2	.2516					8	.2401½	
			4	.2516					15	.2392	
			8	.2517½					30	.2381½	
			15	.2521	SWELL				60	.2373	
									120	.2368	
									240	.2364	
									480	.2361	
JZN	15Aug86	1205	0	.2521	2.0KgCm²		18Aug	0855		.2357	
			.1	.2509							
			.25	.2507½							
			.5	.2506½		R.T.	19Aug	0940	0	.2357	16KgCm²
			1	.2505½					.1	.2325	
			2	.2504½					.25	.2319	
			4	.2503½					.5	.2314	
			8	.2503					1	.2307	
			15	.2502½					2	.2297½	
			30	.2502					4	.2285	
			60	.2501½					8	.2267	
		1405	120	.2501					15	.2246	
		1605	240	.2500					35	.2215	
	16Aug	0800		.2499					60	.2196	
								1140	120	.2178	
								1340	240	.2166	
								1640	420	.2161	
								0810		.2149	

FORM L-126

CONSOLIDATION TEST

Date:__________ Project:____________________ Job No.__________

Boring No.________ Sample No.________ Depth:________ Ring No.________

Description:__________________________ Liquid Limit ________

__________________________ Plastic Limit ________

Test Specimen	Initial	Final
Wet wt sple + ring		
Dry wt sple + ring		
Wt of ring		
Dry wt of sple		
Wt of water		
Water content, %		

Trimmings, Can No.	
Wet wt + tare	
Dry wt - tare	
Tare wt	
Dry wt	
Wt of water	
Water content, %	

A. Specific Gravity________ B. Volume of Sple______ c.c. C. Initial Ht of Sple________ in.

D. Final Ht of Sple_______ in. E. Unit Wet Wt______ lb/ft^3 F. Unit Dry Wt________ lb/ft^3

G. Ht of Solids $= \dfrac{\text{Final Dry Wt Sple}}{A} \times \dfrac{C}{B} =$ ________ in. $\dfrac{1}{G} =$ ________

H. Initial Void Ratio: $= \dfrac{C - G}{G} =$ ________

Percent Saturation:

Before Test $= \dfrac{\text{Initial Wt Water}}{B - \dfrac{\text{Dry Wt Sple}}{A}} \times 100 =$ ________ %

After Test $= \dfrac{\text{Final Wt Water}}{B \times \dfrac{D}{C} - \dfrac{\text{Dry Wt Sple}}{A}} \times 100 =$ ________ %

Consolidometer No: $^{*}P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v $in.^2/day$

Tested By:________

Computed By:________

Checked By:________

CONSOLIDATION TEST
DATA SHEET

Job No. ______ Boring No. ______ Depth ______ Consol. No. ______

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.	Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
B.T.	20 Aug	0815	0	.2119	32 Kg/cm²						
			.1	.2117							
			.25	.2110							
			.50	.2104							
			1	.2095							
			2	.2082							
			4	.2064							
			8	.2039							
			15	.2009							
			30	.1968							
			60	.1918							
		1030	~~120~~ 135	.1875							
			240	.1855							
		420	485	.1840							
		0820		.1826							
	Rebound		0								
	21 Aug	0835	0	.1826	8 Kg/cm²						
	22 Aug	1130		.2026							
	22 Aug	1130	0	.2026	2 Kg/cm²						
				.2263							

Job No. ______ FORM L-127

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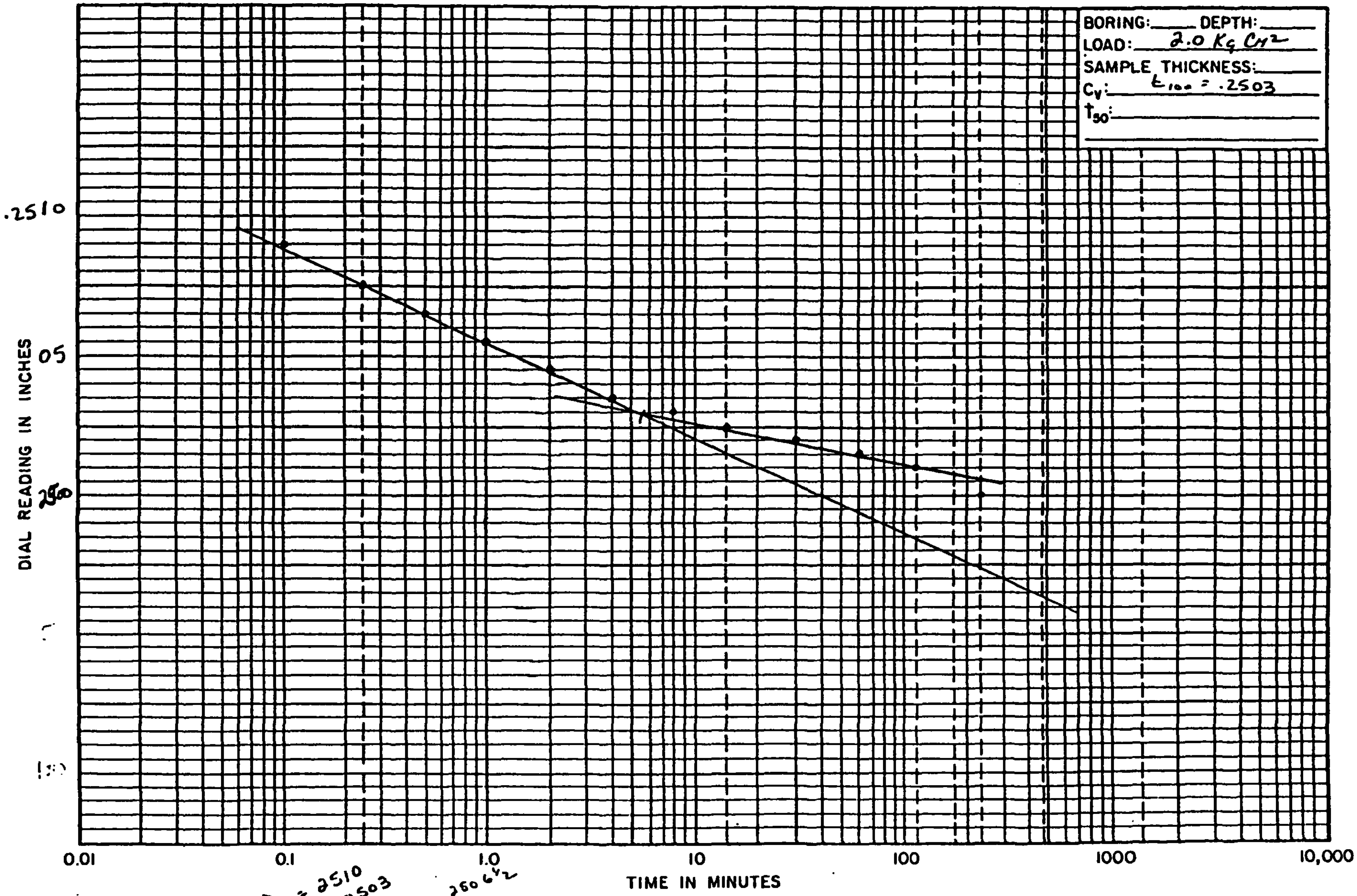

CONSOLIDATION TIME CURVE

PLATE

[redacted] JOB NO. [redacted]

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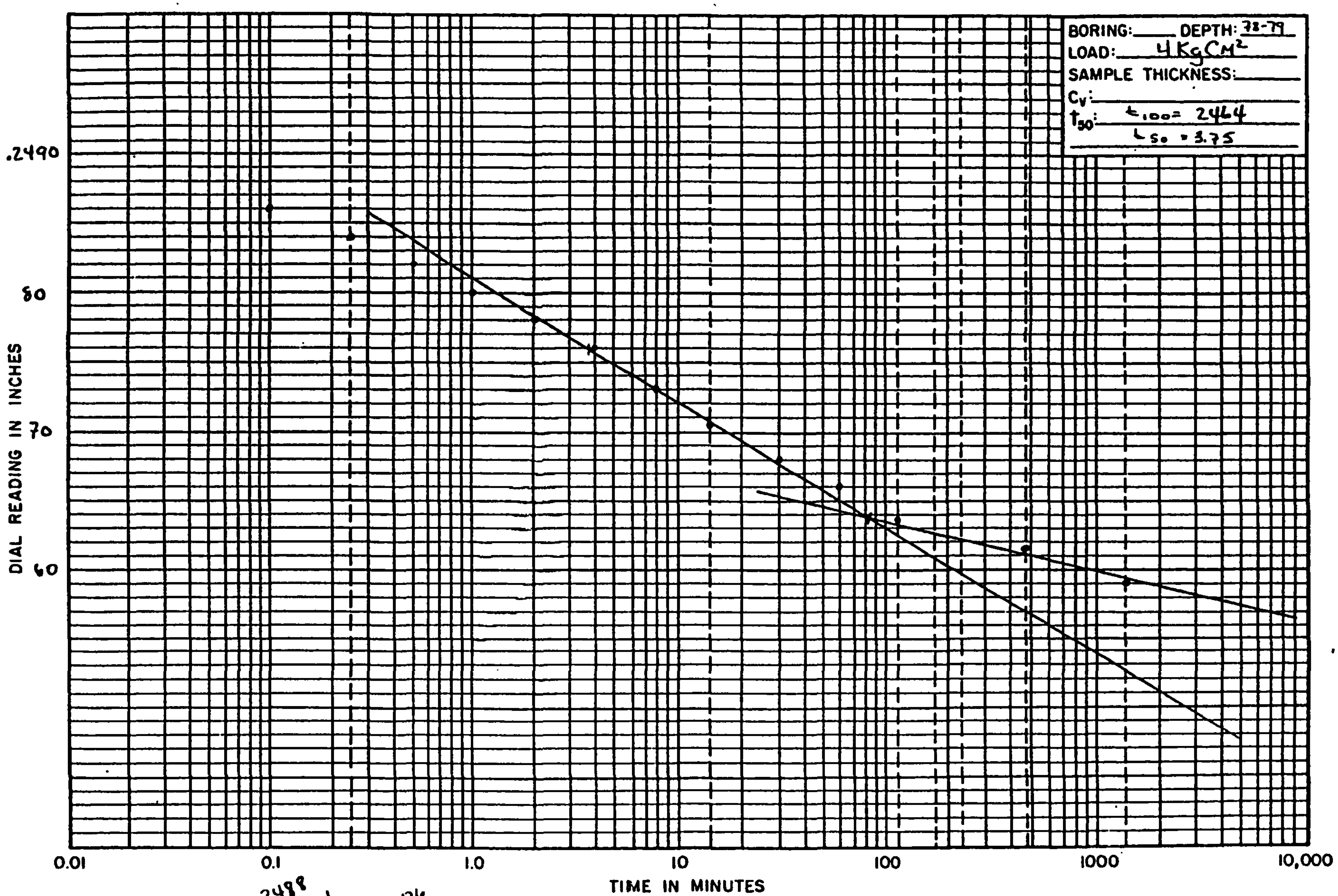

$D_0 = 2488$
$t_{100} = 2464$
$D_{50} = 2476$

CONSOLIDATION TIME CURVE

PLATE

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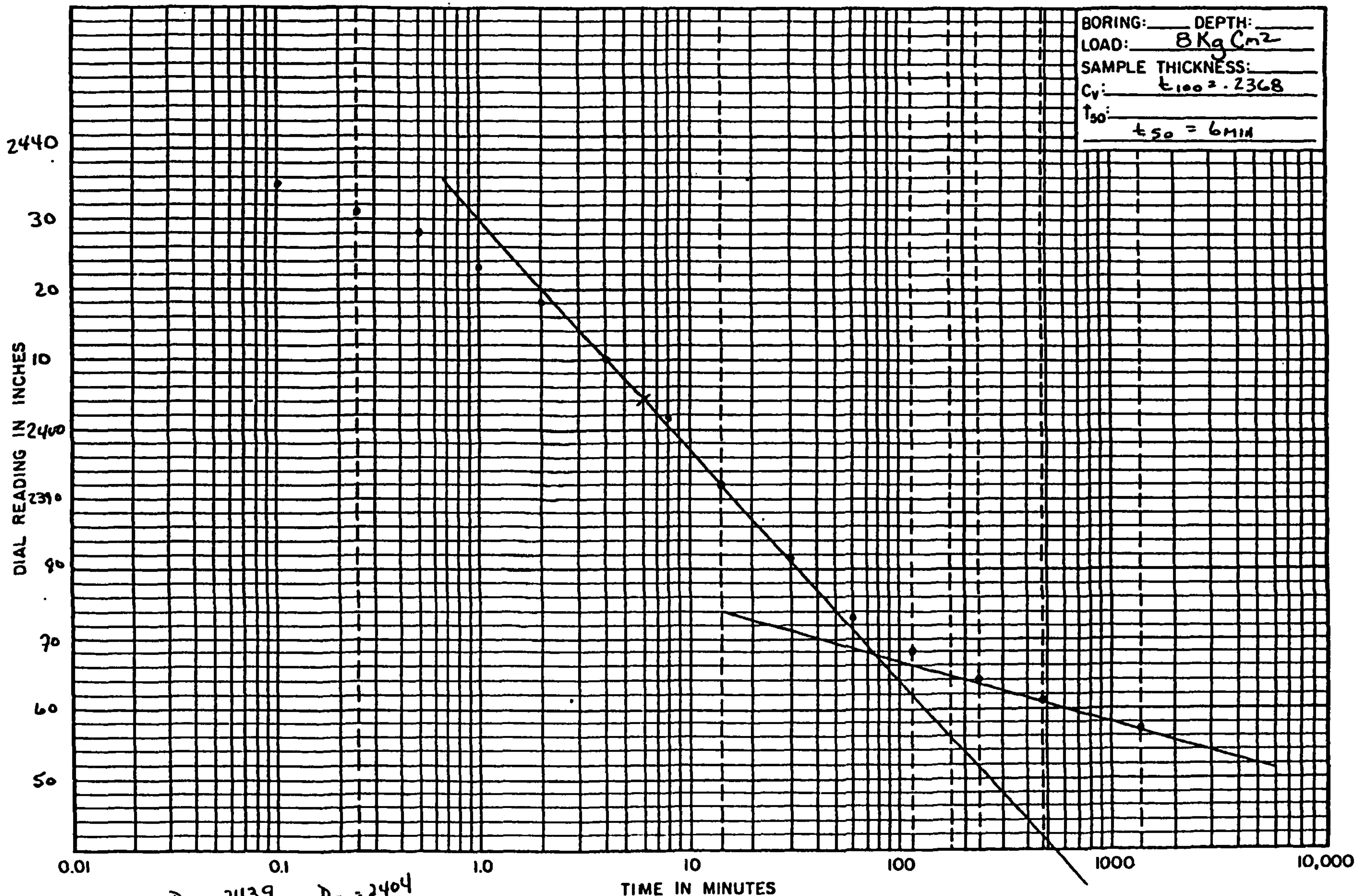

D_0 = 2439 D_{50} = 2404
D_{100} 2368

CONSOLIDATION TIME CURVE

PLATE

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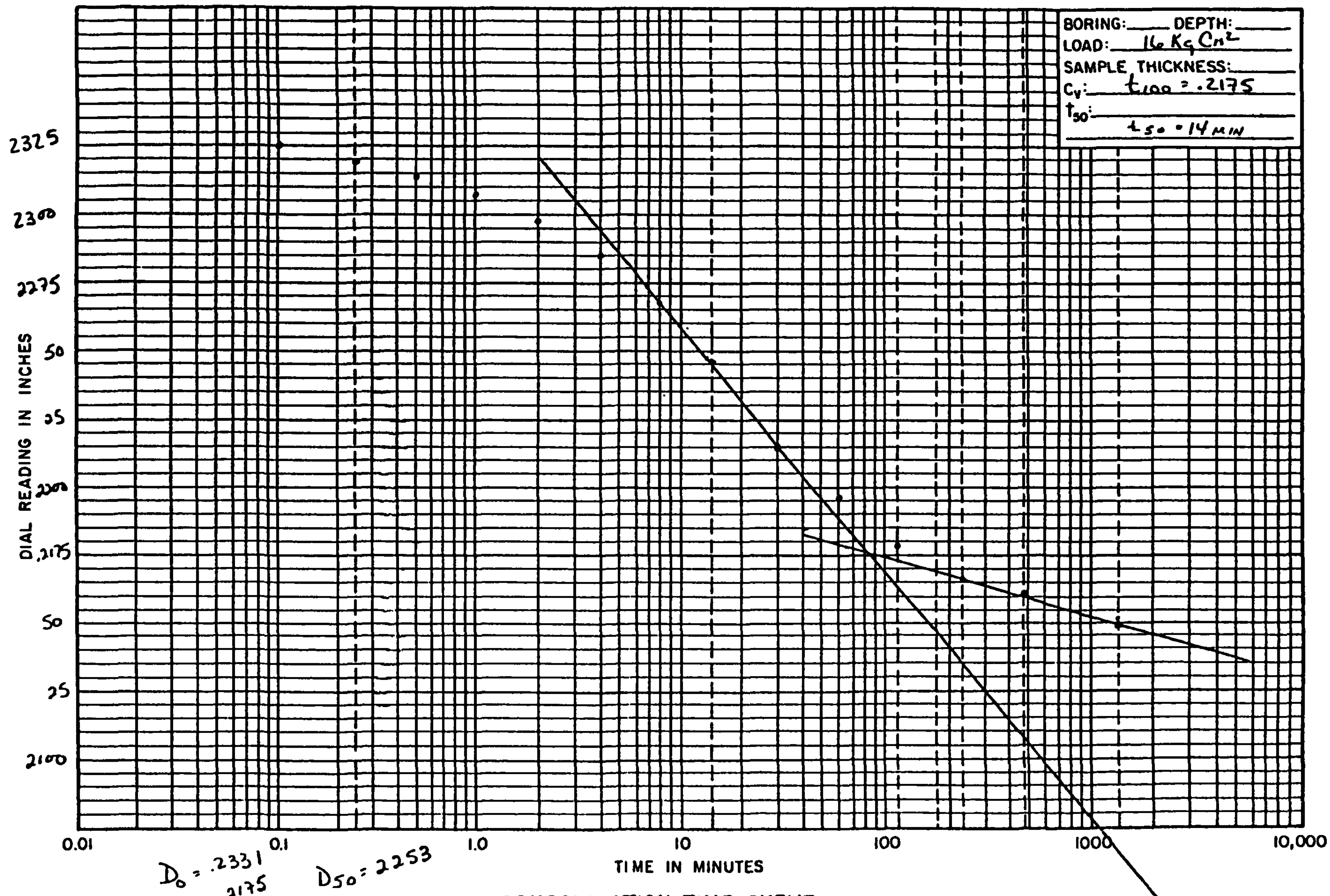

CONSOLIDATION TIME CURVE

PLATE

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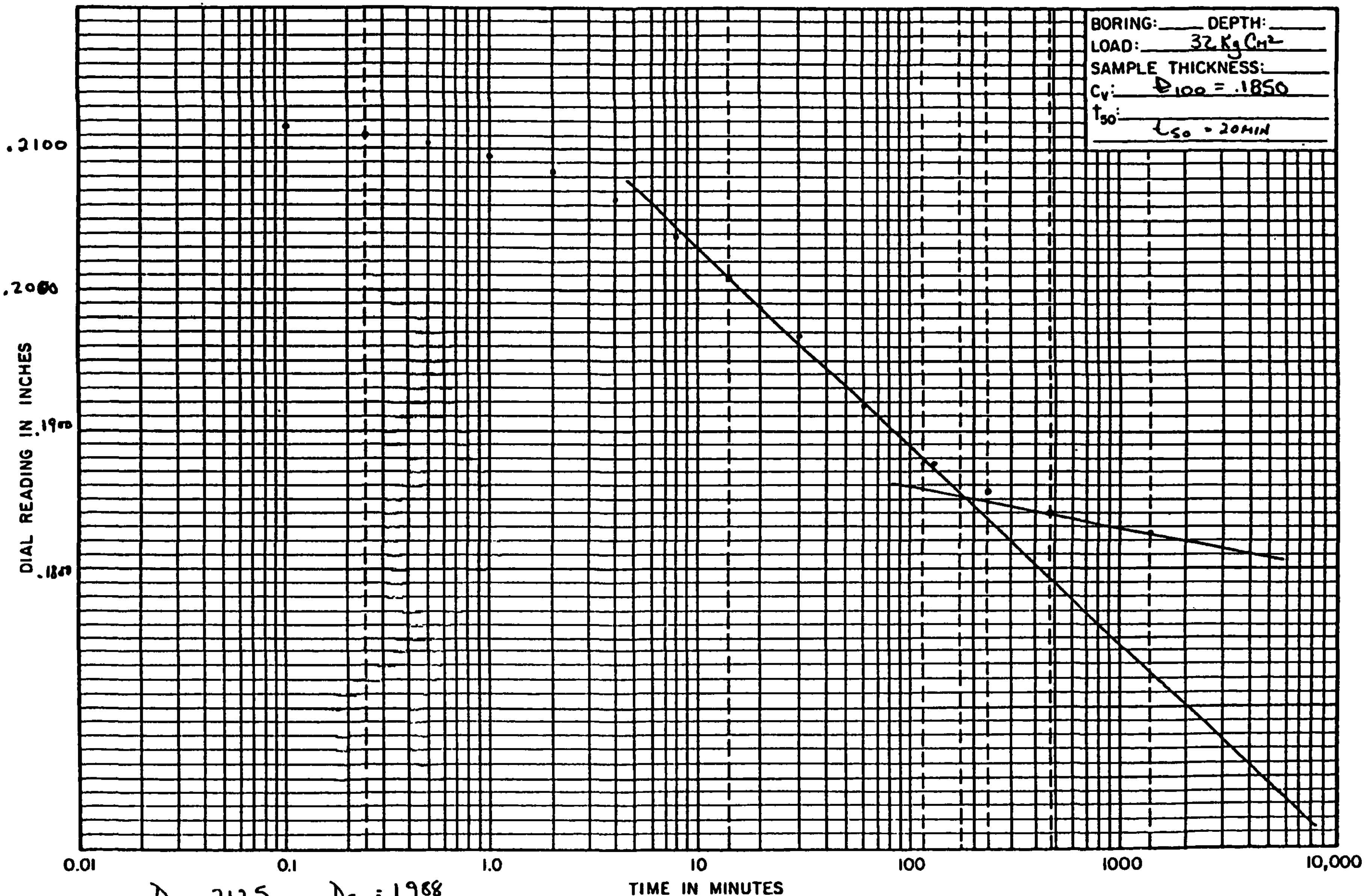


D_0 = 2125 D_{50} : 1988
D_{100} = 1850

CONSOLIDATION TIME CURVE

PLATE

CONSOLIDATION TEST
Version 1.1
================

JOB NO.:   BORING NO.:   SAMPLE NO.:   DEPTH:

TEST SPECIMEN:

	INITIAL	FINAL
WET WEIGHT + TARE =	133.81	132.94
DRY WEIGHT + TARE =	117.09	117.09
TARE WEIGHT =	59.38	59.38
WATER CONTENT =	29.0%	27.5%

TRIMMINGS:

WET WEIGHT + TARE =	51.53
DRY WEIGHT + TARE =	43.56
TARE WEIGHT =	15.49
WATER CONTENT =	28.4%

SPECIFIC GRAVITY = 2.8000
SAMPLE HEIGHT (IN) = 0.7500
SAMPLE DIAMETER (IN) = 1.9700
SAMPLE VOLUME (CC) = 37.4681
HEIGHT OF SOLIDS (IN) = 0.4126
INITIAL VOID RATIO = 0.8179

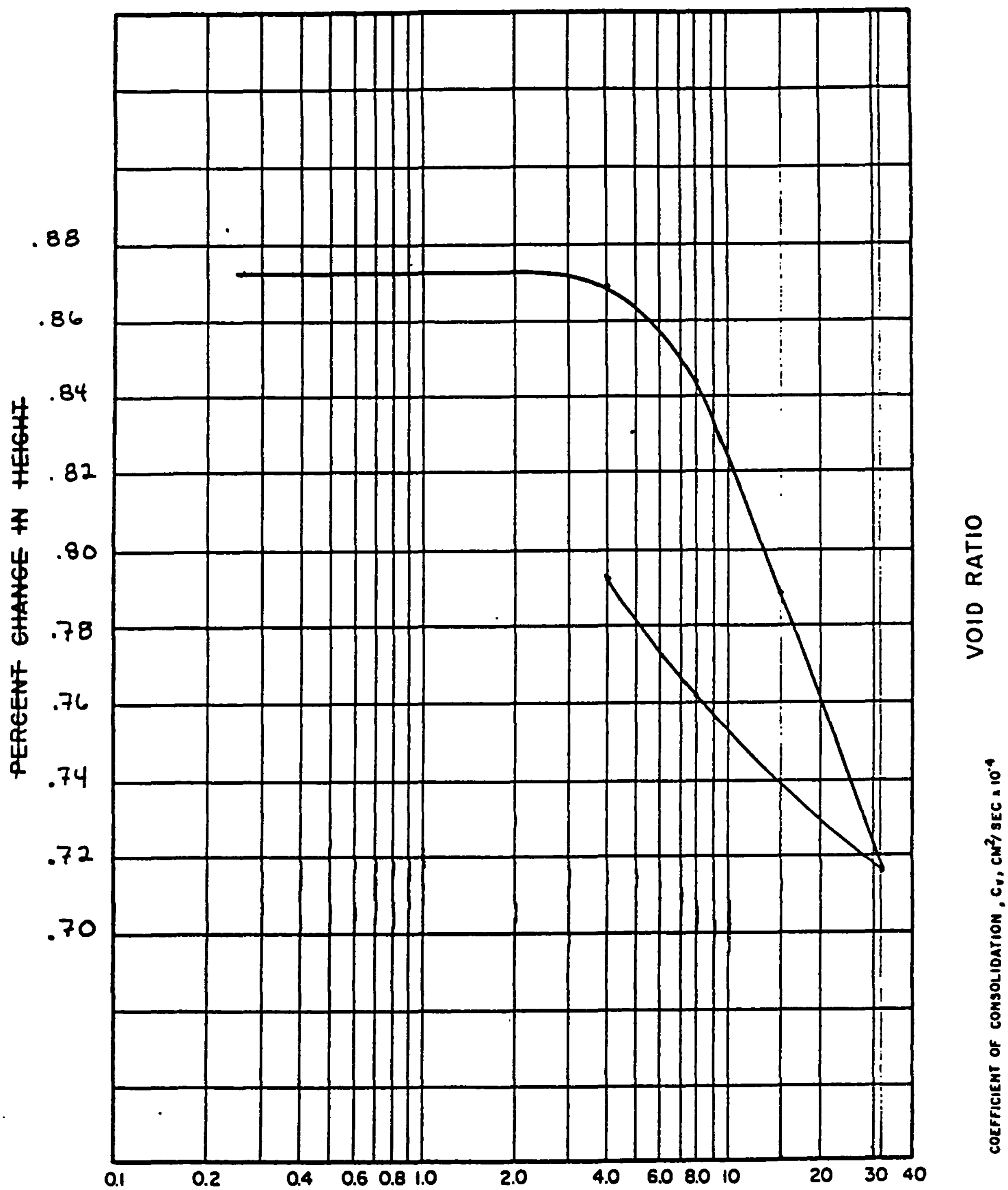
DEGREE OF SATURATION:
INITIAL = 99.2%
FINAL = 99.6%

UNIT WEIGHT OF SPECIMEN:
WET (PCF) = 124.0
DRY (PCF) = 96.1

MACHINE READING	PRESSURE KG/CM^2	DIAL READING	CUM. CHANGE	CORR. CHANGE	VOID RATIO	COEFF. IN^2/DAY
-0.0049	4.000	0.2464	0.0056	0.0007	0.816	10.615
-0.0070	8.000	0.2368	0.0152	0.0082	0.798	6.502
-0.0091	16.000	0.2175	0.0345	0.0254	0.756	2.659
-0.0115	32.000	0.1850	0.0670	0.0555	0.683	1.710
-0.0090	8.000	0.2026	0.0494	0.0404	0.720	0.000
-0.0069	2.000	0.2263	0.0257	0.0188	0.772	0.000

BORING NO: SAMPLE NO:
DEPTH, FT: 80-81
DESCRIPTION: Hard red clay with calcarous nodules, slickensided

UNIT DRY WEIGHT: 93.3 PCF
WATER CONTENT: 27.7 %
LIQUID LIMIT:
PLASTIC LIMIT:



CONSOLIDATION TEST RESULTS

FUGRO GULF, INC.
Consulting Engineers and Geologists

PLATE

CONSOLIDATION TEST

Date: ______ Project: REI P10-4 Job No. ______

Boring No. ______ Sample No. ______ Depth: 80-81 Ring No. 3

Description: Vst. red clay w/calc NODS, SLICKENSIDED

Liquid Limit ______

Plastic Limit ______

Test Specimen	Initial	Final
Wet wt sple + ring	143.75	142.50
Dry wt sple + ring	126.28	126.28
Wt of ring	70.50	70.50
Dry wt of sple		
Wt of water		
Water content, %		

Trimmings, Can No. 605	
Wet wt + tare	64.32
Dry wt - tare	53.67
Tare wt	15.09
Dry wt	
Wt of water	
Water content, %	

A. Specific Gravity ______ B. Volume of Sple 37.318 c.c. C. Initial Ht of Sple 0.747 in.

D. Final Ht of Sple ______ in. E. Unit Wet Wt ______ lb/ft^3 F. Unit Dry Wt ______ lb/ft^3

G. Ht of Solids = $\frac{\text{Final Dry Wt Sple}}{A} \times \frac{C}{B}$ = 0.3988 in. $\frac{1}{G}$ = ______

H. Initial Void Ratio: = $\frac{C - G}{G}$ = 0.8733

d = 1.97

Percent Saturation:

Before Test = $\dfrac{\text{Initial Wt Water}}{B - \frac{\text{Dry Wt Sple}}{A}} \times 100$ = ______ %

After Test = $\dfrac{\text{Final Wt Water}}{B \times \frac{D}{C} - \frac{\text{Dry Wt Sple}}{A}} \times 100$ = ______ %

Consolidometer No: $^{*}P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v $in.^2/day$
.0000	0	.2500	—	—					
.0003	.25		—	—					
.0007	.5		—	—					
.0017	1		—	—					
.0035	2		—	—					
.0060	4	.2576	.0076	.0016			0.869	5.5	7.162
.0087	8	.2705	.0205	.0118			0.844	18.0	2.129
.0110	16	.2945	.0445	.0335			0.789	26.0	1.388
.0134	32	.3260	.0760	.0626			0.716	28.0	1.186
.0107	8	.3052	.0552	.0445			0.762		
.0090	4	.2911	.0411	.0321			0.793		

Tested By: RW

Computed By: RW

Checked By: RC

CONSOLIDATION TEST
DATA SHEET

Job No. ______ Boring No. P10-4 Depth 80-81 Consol. No. 3

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
JZN	15Aug	1308	0	.2500	.25KgCm²
			.1	.2508	
			.25	.2509	
			.5	.2510	
	add	H2o →	1	.2510	
			2	.2500	SWELL
			4		
JZN		1310	0	.2500	.5KgCm²
			.1	.2504	
			.25	.2505	
			.5	.2504	
			1	.2503	
			2	.2501	SWELL
		1313	0	.2501	10KgCm²
			.1	.2510	
			.25	.2511	
			.5	.2511½	
			1	.2511½	
			2	.2511	
			4	.2510	SWELL
JZN	15Aug	1315	0	.2510	2.0KgCm²
			.1	.2525½	
			.25	.2527	
			.5	.2528½	
			1	.2529½	
			2	.2530½	
			4	.2531	
			8	.2530	
			15		SWELL

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
JZN	15Aug	1330	0	.2520	4.0KgCm²
			.1	.2551	
			.25	.2553½	
			.5	.2556	
			1	.2558½	
			2	.2561	
			4	.2564	
			8	.2568½	
			15	.2571	
			40	.2574½	
		1430	60	.2525½	
		1530	120	.2577	
		1730	240	.2578	
	16Aug	0800	1110	.2580	
	16Aug	0910	0	.2580	8KgCm²
			.1	.2609	
			.25	.2612	
			.5	.2616	
			1	.2620½	
			2	.2626	
			4	.2633½	
			8	.2643	
			15	.2654	
			30	.2667	
			60	.2682	
			120	.2699	
			240		
			480	.2709	
			1440	.2714	
	17Aug	0810	0	.2714	16KgCm²
			.1	.2748	
			.25	.2752	
			.5	.2757	
			1	.2763	
			2	.2772	
			4	.2784	
			8	.2800	
			15	.2821	
			30	.2850	
			60	.2884	
			120	.2915	
			240	.2938	
			480	.2952	
		0830	1460	.2963	

CONSOLIDATION TEST

Date: ______________ Project: ______________________________ Job No. __________

Boring No. ________ Sample No. ________ Depth: ____________ Ring No. __________

Description: ____ Liquid Limit __________

____ Plastic Limit __________

Test Specimen	Initial	Final
Wet wt sple + ring		
Dry wt sple + ring		
Wt of ring		
Dry wt of sple		
Wt of water		
Water content, %		

Trimmings, Can No.	
Wet wt + tare	
Dry wt - tare	
Tare wt	
Dry wt	
Wt of water	
Water content, %	

A. Specific Gravity________ B. Volume of Sple______ c.c. C. Initial Ht of Sple__________in.

D. Final Ht of Sple________in. E. Unit Wet Wt______lb/ft^3 F. Unit Dry Wt__________lb/ft^3

G. Ht of Solids = $\dfrac{\text{Final Dry Wt Sple}}{A} \times \dfrac{C}{B}$ = __________in. $\dfrac{1}{G}$ = __________

H. Initial Void Ratio: = $\dfrac{C - G}{G}$ = __________

Percent Saturation:

Before Test = $\dfrac{\text{Initial Wt Water}}{B - \dfrac{\text{Dry Wt Sple}}{A}} \times 100$ = ________%

After Test = $\dfrac{\text{Final Wt Water}}{B \times \dfrac{D}{C} - \dfrac{\text{Dry Wt Sple}}{A}} \times 100$ = ________%

Consolidometer No: $^{*}P = 70.9(C-J)^2/N$

Load No. or Gage Reading	Pressure T/ft^2	Dial Reading in.	J' Cum. Dial Change in.	J Corr. Dial Change in.	K Cons. in./in. = J/C	L Void Ratio Change = J/G	M Void Ratio = H-L	N t_{50} min.	P* c_v $in.^2/day$

Tested By: __________
Computed By: __________
Checked By: __________

CONSOLIDATION TEST
DATA SHEET

Job No. ________ Boring No. ________ Depth ________ Consol. No. ________

Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.	Observ. By	Date	Time	Elapsed Time min.	Dial Reading in.	Load No.
B.T.	18 Aug	0845	0	.2963	32 Kg/cm²						
			.1	.2995							
			.25	.3001							
			.5	.3008							
			1	.3016							
			2	.3027							
			4	.3043							
			8	.3064							
			15	.3090							
			30	.3128½							
			60	.3177							
			120	.3225							
		1225	220	.3256							
		1700	495	.3278							
	19 Aug	0924		.3298							
	Rebound										
B.T.	19 Aug	0930	0	.3298	8 Kg cm²						
		0810		.3052							
B.T.	20 Aug	0810	0	.3052	4 Kg cm²						
B.T.	21 Aug	0820		.2911							

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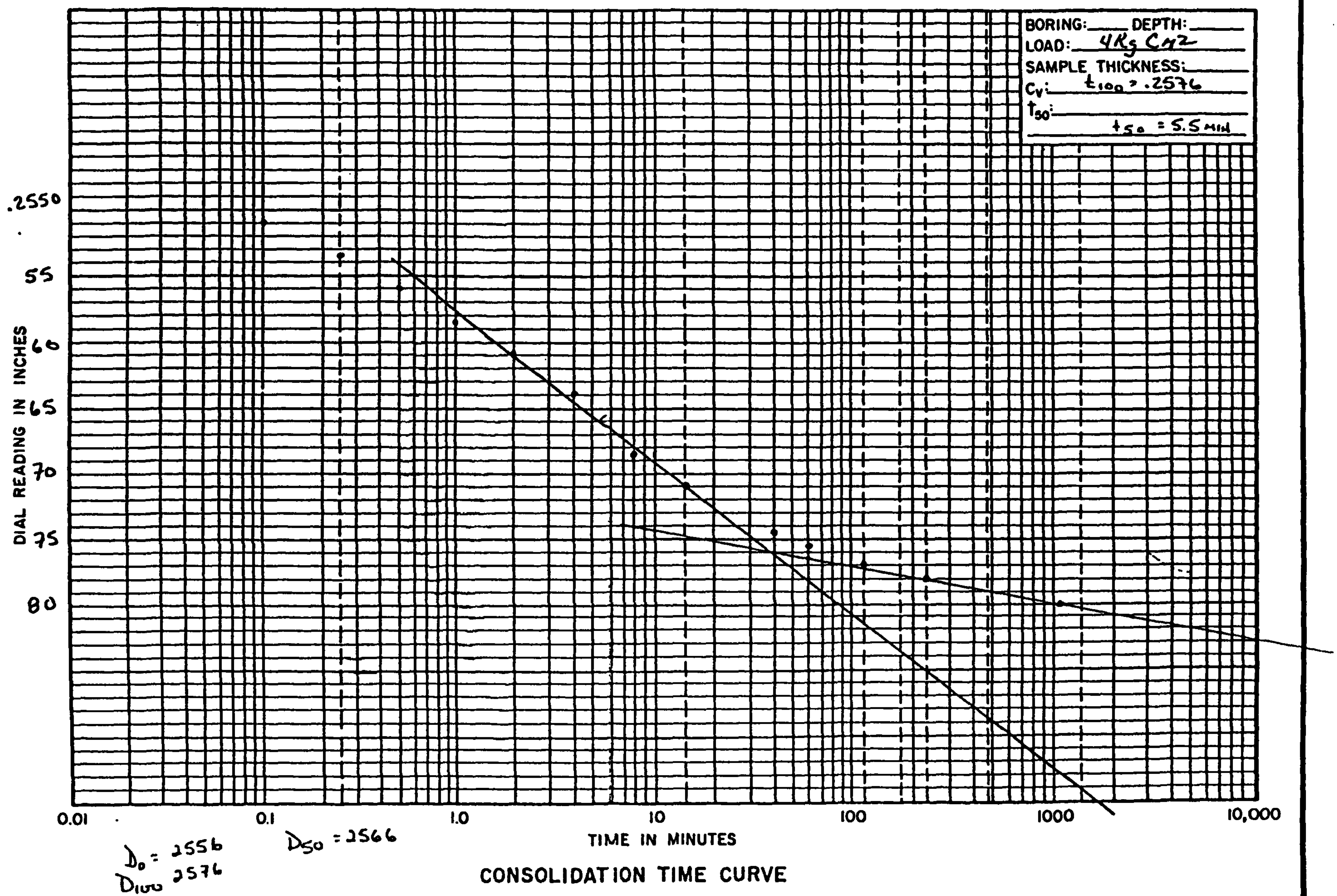

CONSOLIDATION TIME CURVE

PLATE

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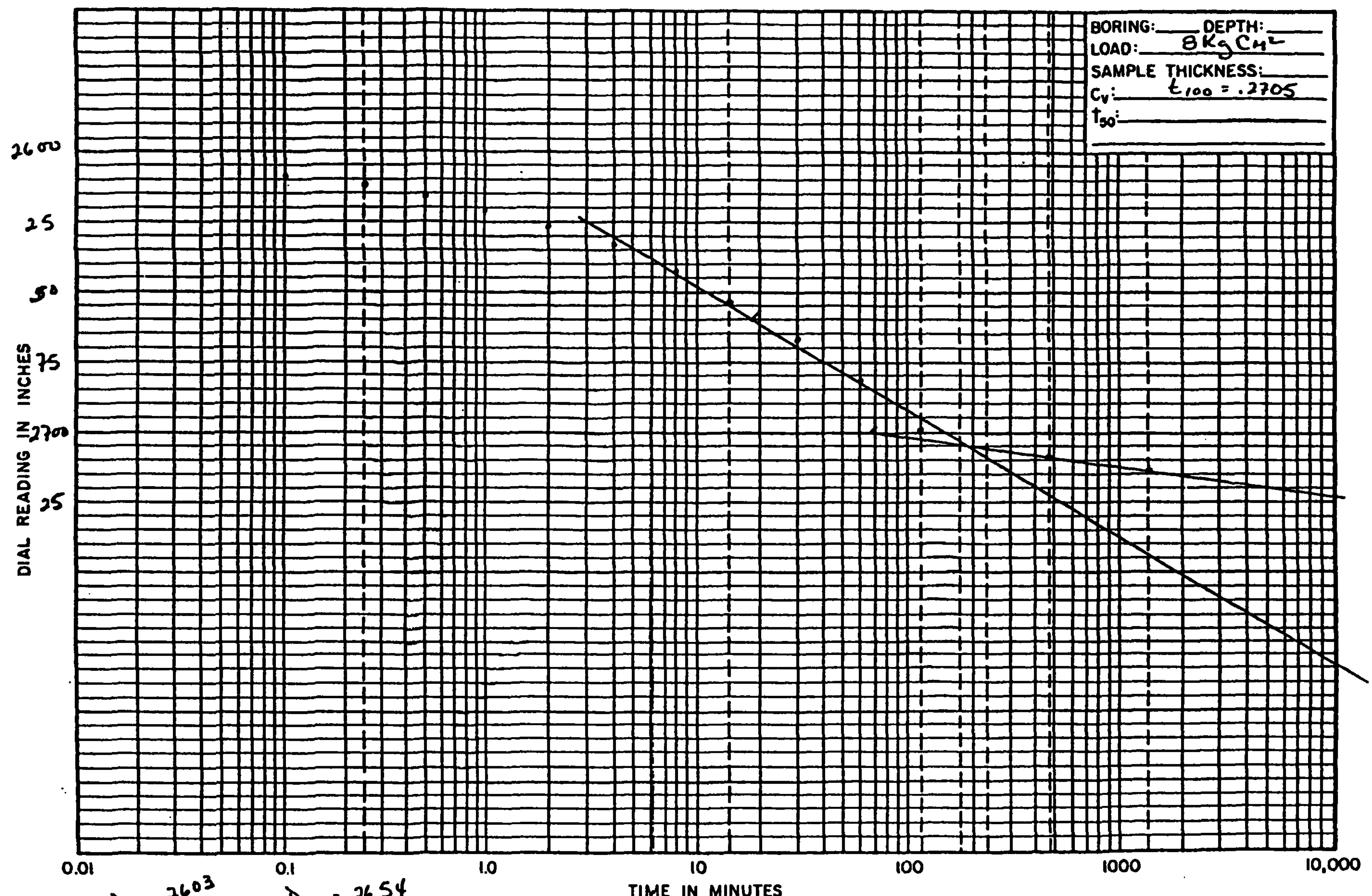

CONSOLIDATION TIME CURVE

D_0 = 2603
D_{100} = 2705
D_{50} = .2654

PLATE

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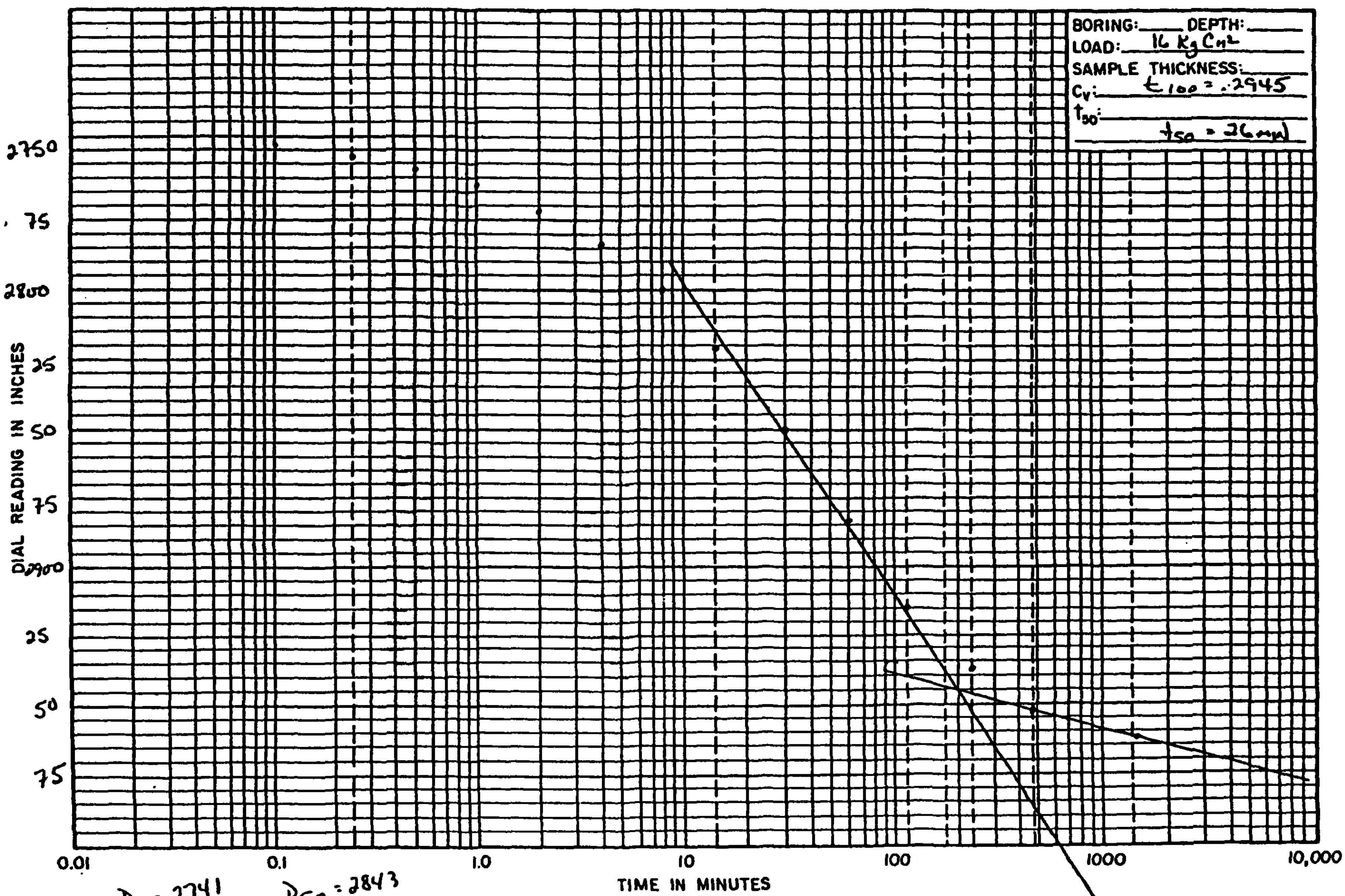

$D_o = 2741$ $D_{50} = 2843$
$D_{100} = 2945$

CONSOLIDATION TIME CURVE

PLATE

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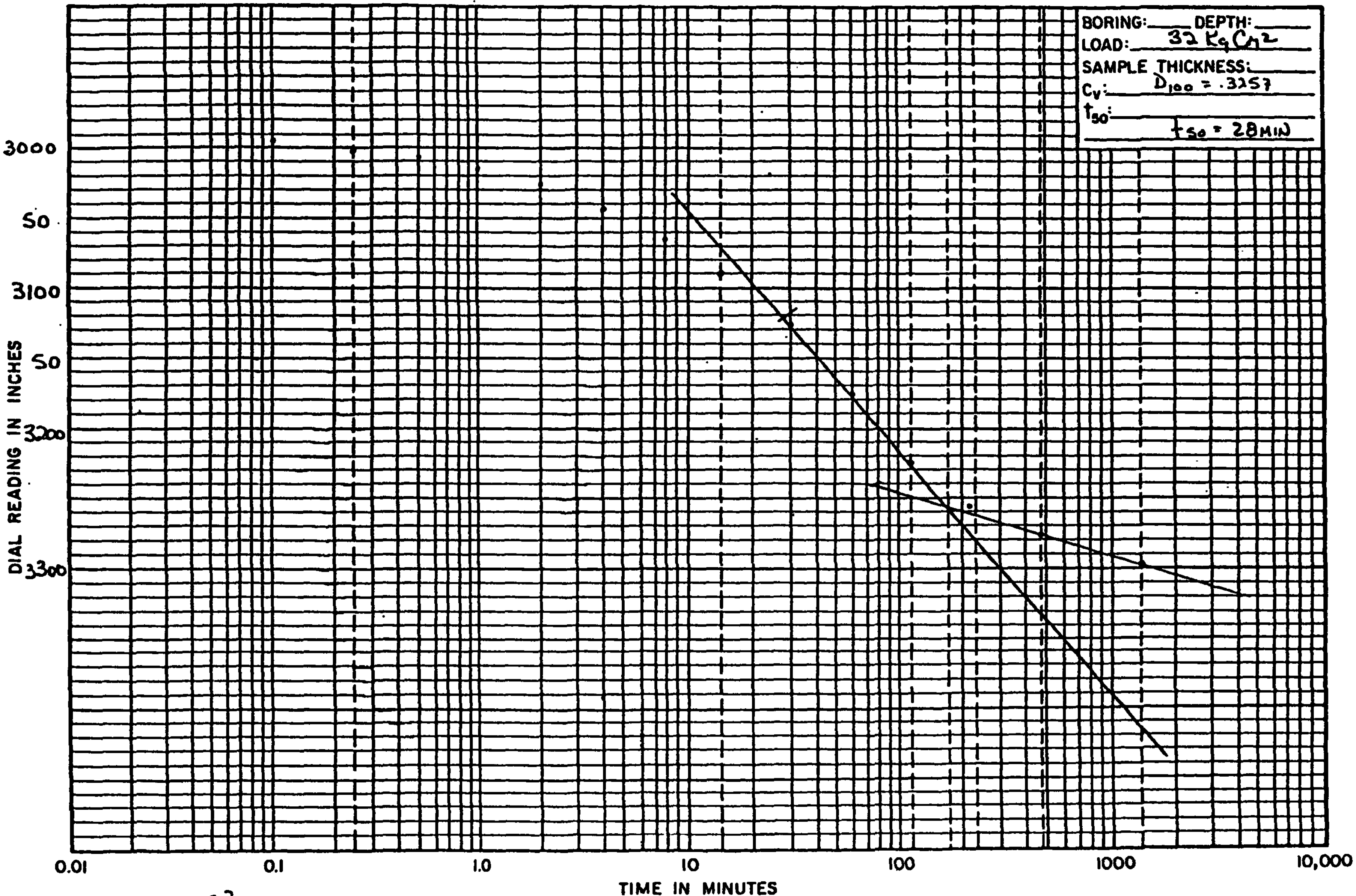

.3257
.2986

CONSOLIDATION TIME CURVE

PLATE

CONSOLIDATION TEST

Version 1.1

JOB NO.: BORING NO.: SAMPLE NO.: DEPTH:

TEST SPECIMEN:

	INITIAL	FINAL
WET WEIGHT + TARE =	143.75	142.50
DRY WEIGHT + TARE =	126.28	126.28
TARE WEIGHT =	70.50	70.50
WATER CONTENT =	31.3%	29.1%

TRIMMINGS:

WET WEIGHT + TARE =	64.37
DRY WEIGHT + TARE =	53.67
TARE WEIGHT =	15.09
WATER CONTENT =	27.7%

SPECIFIC GRAVITY = 2.8000
SAMPLE HEIGHT (IN) = 0.7470
SAMPLE DIAMETER (IN) = 1.9700
SAMPLE VOLUME (CC) = 37.3183
HEIGHT OF SOLIDS (IN) = 0.3988
INITIAL VOID RATIO = 0.8733

DEGREE OF SATURATION:
INITIAL = 100.4%
FINAL = 102.7%

UNIT WEIGHT OF SPECIMEN:
WET (PCF) = 122.5
DRY (PCF) = 93.3

MACHINE READING	PRESSURE KG/CM^2	DIAL READING	CUM. CHANGE	CORR. CHANGE	VOID RATIO	COEFF. IN^2/DAY
-0.0060	4.000	0.2424	0.0076	0.0016	0.869	7.162
-0.0087	8.000	0.2295	0.0205	0.0118	0.844	2.129
-0.0110	16.000	0.2055	0.0445	0.0335	0.789	1.388
-0.0134	32.000	0.1740	0.0760	0.0626	0.716	1.186
-0.0107	8.000	0.1948	0.0552	0.0445	0.762	0.000
-0.0090	4.000	0.2089	0.0411	0.0321	0.793	0.000

APPENDIX 4

CALCULATIONS OF RESPONSE IN THE MIDDLE CLAYEY ZONE TO 7-DAY PUMP TEST OF WELL REI-10-1

NEUMAN WITHERSPOON (1972) ANALYSIS OF P-10-2 RESPONSE

Lower Silty Sand Zone Hydrologic Characteristics

Based on the analysis of the response in GW-25 to pump testing REI-10-1 in August and September (see Section 6.3), the aquifer coefficient valuse provided below were used to represent the lower silty sand zone in the vicinity of the pumping well:

Transmissivity, $T = 2000$ gpd/ft $= 2.88\ cm^2/sec$

Storage Coefficient, $S = 1.6 \times 10^{-4}$

Dimensions

Based on Figure 1 of Neuman and Witherspoon (1972)

Radial distance from pumped well, $r = 21$ feet

Vertical distance from top of pumped aquifer, $z = 32$ feet

Analysis

Calculations provided below were performed at three separate times, 8000, 9000, and 10000 minutes after pumping started:

Parameter	Time After Pumping Started, t (minutes)		
	8000	9000	10000
Drawdown in Pumped Zone, s (1)			
$u = r^2 S / T t$	1.16×10^{-5}	1.035×10^{-5}	9.31×10^{-5}
$W(n)$ (from Tables)	10.7	10.85	11.0
$s = Q W(n) / 4$ „ T	10.37	10.51	10.66
Drawdown in Aquiclude, s' (2)			
s'/s	0.0116	0.0343	0.0507
$t_D = T t / S r^2$	2.15×10^{-4}	2.4×10^{-4}	2.7×10^{-4}
t_D' (3)	8.2×10^{-2}	1.3×10^{-1}	1.9×10^{-1}
' $= (z^2/t)\, t_D'$ (cm^2/sec)	0.163	0.229	0.301
$K' =$ ' S_s' (4) (cm^2/sec)	5×10^{-7}	7×10^{-7}	9×10^{-7}

(1) Based on Theis response using pumped zone characteristics

(2) Measured response in P-10-2 piezometer after factoring out precipitation loading response and reverse water level response as shown in Figure 6-39

(3) From Neuman and Witherspoon (1972) Figure 3 (attached)

(4) $S_s' = 3 \times 10^{-6}\ cm^{-1}$ from consolidation test results, Table 5-1

SLUG TEST ANALYSIS OF PRECIPITATION LOADING RESPONSE

Supporting calculations for P-10-2 using the method of Cooper et al (1967)

The type curve for alpha = 10^{-2} ($S=5x10^{-4}$) and alpha = 10^{-4} ($S=5x10^{-6}$) was fit to the latter portion of the response. The corresponding time, t, at which $Tt/r_c^2 = 1.0$ was 310 minutes and 183 minutes respectively. Consequently, transmissivity, T, can be estimated as:

$$T = 1.0 * r_c^2/t = (0.052083 \text{ ft.})^2/310 \text{ minutes}$$

$$T = 8.75x10^{-6} \text{ ft.}^2/\text{minute and}$$

$$T = 1.0 * r_c^2/t = (0.052083 \text{ ft.})^2/183 \text{ minutes}$$

$$T = 1.48x10^{-5} \text{ ft.}^2/\text{minute}$$

and Hydraulic conductivity can be calculated as:

$$K \text{ (cm/sec)} = 0.508\ T(ft^2/min)/b(ft) = 0.508*8.75x10^{-6}/2.0$$
$$= 2.22x10^{-6} \text{ (cm/sec) and}$$

$$K \text{ (cm/sec)} = 0.508*1.48x10^{-5}/2.0$$
$$= 3.765x10^{-6} \text{ (cm/sec)}$$

Supporting calculations for P-10-2 using the method of Hvorslev (1951):

The Hvorslev method involves fitting a straight line to the semilog plot of H/H_o versus time where H/H_o, the proportion of recovery remaining, is plotted on the log scale. The basic time lag, T_L, is defined as the time corresponding to $H/H_o = 0.37$. For a piezometer screened in a unit bounded by an impermeable unit, the hydraulic conductivity conductivity, K, is estimated as:

$$K = d^2 \ln(4*L/D)/8*L*T_L$$

where d is the diameter *of* the casing in which water level changes occur, L is the length of the screened interval, and D is the diameter of the drill hole in which the screened interval is completed.

A straight line was fit to the response from 0 to 820 minutes. The estimated value for T_L was 322 minutes. Therefore,

$$K = (.10417)^2 \ln(4*2/0.45)/(8*2*322)$$

$$K = 6.06x10^{-6} \text{ ft/min} = 3.08x10^{-6} \text{ cm/sec.}$$

Supporting calculations for P-10-4 using the method of Hvorslev (1951):

For a piezometer screened in a uniform isotropic soil, the hydraulic conductivity conductivity, K, is estimated as:

$$K = d^2 \ln(2*L/D)/8*L*T_L$$

where d is the diameter of the casing in which water level changes occur, L is the length of the screened interval, and D is the diameter of the drill hole in which the screened interval is completed.

A straight line was fit to the response from 0 to 3000 minutes. The estimated value for T_L was 13200 minutes. Therefore,

$$K = (.16667)^2 \ln(2*2/0.45)/(8*2*13200)$$

$$K = 2.87 \times 10^{-7} \text{ ft/min} = 1.46 \times 10^{-7} \text{ cm/sec.}$$

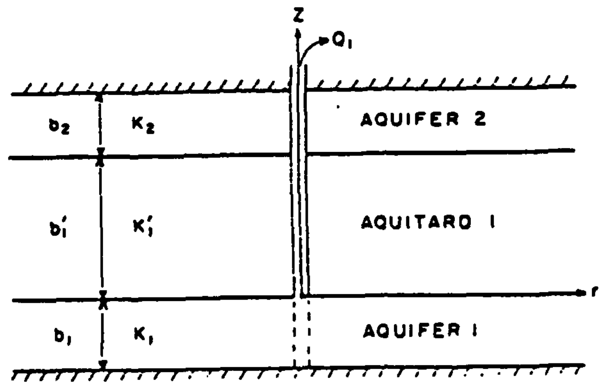

Fig. 1. A schematic diagram of a two-aquifer system.

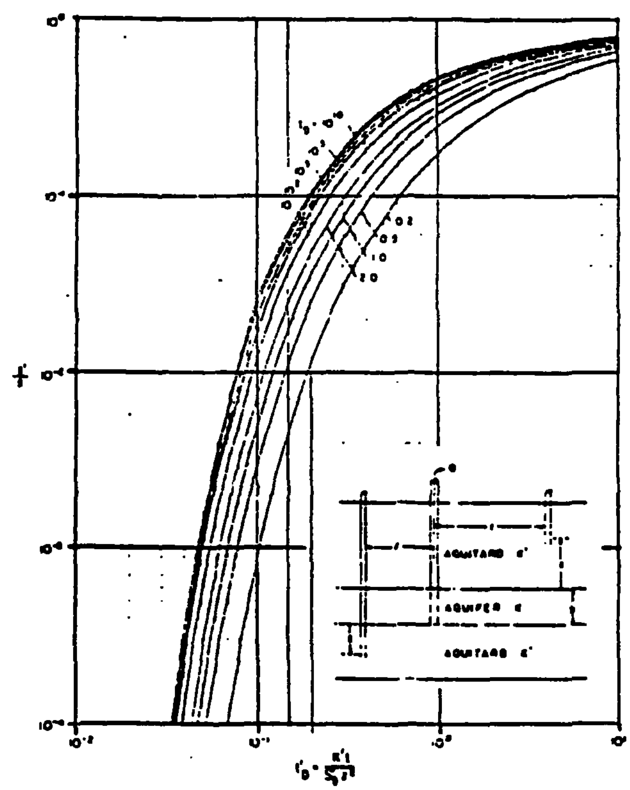

Fig. 3. The variation of s'/s with t_D' for a semi-infinite aquitard.

Figures from Neuman and Witherspoon (1972)

APPENDIX 5

SLUG TEST ANALYSIS CALCULATIONS

SLUG TEST ANALYSIS USING THE METHOD OF COOPER ET AL (1967)

Supporting calculations for P-10-3:

The type curve for alpha = 10^{-3} was fit to the early portion of the response test from 1 to 1000 minutes. The corresponding time, t, at which $Tt/r_c^2 = 1.0$ was 1620 minutes. Consequently, transmissivity, T, can be estimated as:

$$T = 1.0 * r_c^2/t = (0.0833 \text{ ft.})^2/1620 \text{ minutes}$$

$$T = 4.287\text{x}10^{-6} \text{ ft.}^2/\text{minute}$$

and Hydraulic conductivity can be calculated as:

$$K = T/b = 4.287\text{x}10^{-6}/2.0 = 2.143\text{x}10^{-6} = 1.09\text{x}10^{-6} \text{ cm/sec.}$$

The type curve for alpha = 10^{-4} was fit to the latter portion of the slug test from 3000 to 30000 minutes. The corresponding time, t, at which $Tt/r_c^2 = 1.0$ was 57,500 minutes. Therefore,

$$T = (.0833 \text{ ft})^2/57500 \text{ minutes} = 1.208\text{x}10^{-7} \text{ ft}^2/\text{minute and}$$

$$K = 1.208\text{x}10^{-7}/2.0 = 6.039\text{x}10^{-8} = 3.07\text{x}10^{-8} \text{ cm/sec.}$$

Supporting calculations for P-10-4:

The type curve for alpha = 10^{-4} was fit to the slug test response from 20 to 20,000 minutes. The corresponding time, t, at which $Tt/r_c^2 = 1.0$ was 20,000 minutes. Therefore,

$$T = (.0833 \text{ ft})^2/20000 \text{ minutes} = 3.47\text{x}10^{-7} \text{ ft}^2/\text{minute and}$$

$$K = 3.47\text{x}10^{-7}/2.0 = 1.74\text{x}10^{-7} = 8.82\text{x}10^{-8} \text{ cm/sec.}$$

SLUG TEST ANALYSIS USING THE METHOD OF HVORSLEV (1951)

The Hvorslev method involves fitting a straight line to the semilog plot of H/H_o versus time where H/H_o, the proportion of recovery remaining, is plotted on the log scale. The basic time lag, T_L, is defined as the time corresponding to $H/H_o = 0.37$. For a screened piezometer in uniform isotropic soil, the hydraulic conductivity conductivity, K, is estimated as:

$$K = d^2 \ln(2*L/D)/8*L*T_L$$

where d is the diameter of the casing in which water level changes occur, L is the length of the screened interval, and D is the diameter of the drill hole in which the screened interval is completed.

Supporting calculations for P-10-3:

A straight line was fit to the early response data from 0 to 2000 minutes. The estimated value for T_L was 8000 minutes. Therefore,

$$K = (.16667)^2 \ln(2*2/0.45)/(8*2*8000)$$

$$K = 4.74x10^{-7} \text{ ft/min} = 2.41x10^{-7} \text{ cm/sec.}$$

The estimated value for T_L from the straight line fit to the response data from 4,000 to 40,000 minutes was 216,000 minutes. Therefore,

$$K = (.16667)^2 \ln(2*2/0.45)/(8*2*216,000)$$

$$K = 1.756x10^{-8} \text{ ft/min} = 8.92x10^{-9} \text{ cm/sec.}$$

Supporting calculations for P-10-4:

A straight line was fit to the response data from 0 to 18,000 minutes. The estimated value for T_L was 97000 minutes. Therefore,

$$K = (.16667)^2 \ln(2*2/0.45)/(8*2*97000)$$

$$K = 3.91x10^{-8} \text{ ft/min} = 1.99x10^{-8} \text{ cm/sec.}$$

The estimated value for T_L from the straight line fit to the entire response data from 0 to 43,000 minutes was 139,500 minutes. Therefore,

$$K = (.16667)^2 \ln(2*2/0.45)/(8*2*139,500)$$

$$K = 2.72x10^{-8} \text{ ft/min} = 1.38x10^{-8} \text{ cm/sec.}$$